TARDEC

---TECHNICAL REPORT---

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TARDEC

Electromechanical Suspension Performance Testing

By Wesley W. Bylsma

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U.S. Army Tank-Automotive Research,
Development, and Engineering Center
Detroit Arsenal
Warren, Michigan 48397-5000

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W. Bylsma, J. Beno, D. Weeks, D. Bresie, A. Guenin, M.E. Raymond

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University of Texas-Center for Electromechanics
10100 Burnet Rd./B133
Austin, TX 78758

U.S. Army Yuma Proving Grounds
ATTN: STEYP-MT-EN/B2660
Yuma, AZ 85365-9113

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Under contract DAAE07-98-C-L020 testing was conducted at the U.S. Army Yuma Proving Grounds by the U.S. Army Tank-automotive and Armaments Command, Research, Development and Engineering Center and the University of Texas Center for Electromechanics during 8, 9, and 10 November 1999 between an active (electromechanical suspension) and passive High Mobility Multi-Purpose Wheeled Vehicle (HMMWV) to determine performance improvements. Two tests, RMS Courses and Lane Change Maneuver, produced the most complete performance results for Ride Quality and Maneuverability determination. For the Lane Change Maneuver, the active HMMWV has much less sprung mass (frame) acceleration, over 5 times reduction at higher speeds, than the passive HMMWV. For the active HMMWV, sprung mass acceleration remains mostly constant at around 0.1 g's to 55 MPH while the passive HMMWV shows noticeable increases, at times in excess of 1 g. For the RMS Courses, a comparison shows a 5 times reduction in absorbed power over courses 2 to 5 with the active HMMWV. The active HMMWV has much less sprung mass acceleration, over 4 times reduction at higher speeds, than the passive HMMWV. For the active HMMWV it remains mostly constant at around 0.75 g's to higher speeds while the passive HMMWV shows noticeable increases, at times in excess of 2 g's. Total peak power usage was in the range of 3 kW (RMS and Lane Change Maneuver Courses) and total peak regeneration in the range of 6 kW (RMS Courses) for the active suspension.

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Electromechanical Suspension Performance Testing

W. Bylsma
U.S. Army Tank-automotive and Armaments Command

J. Beno, D. Weeks, D. Bresie, A. Guenin
University of Texas Center for Electromechanics

M.E. Raymond
U.S. Army Yuma Proving Grounds

ABSTRACT
Under contract DAAE07-98-C-L020 testing was conducted at the U.S. Army Yuma Proving Grounds by the U.S. Army Tank-automotive and Armaments Command, Research, Development and Engineering Center and the University of Texas Center for Electromechanics during 8, 9, and 10 November 1999 between an active (electromechanical suspension) and passive High Mobility Multi-Purpose Wheeled Vehicle (HMMWV) to determine performance improvements. Two tests, RMS Courses and Lane Change Maneuver, produced the most complete performance results for Ride Quality and Maneuverability determination. For the Lane Change Maneuver, the active HMMWV has much less sprung mass (frame) acceleration, over 5 times reduction at higher speeds, than the passive HMMWV. For the active HMMWV, sprung mass acceleration remains mostly constant at around 0.1 g's to 55 MPH while the passive HMMWV shows noticeable increases, at times in excess of 1 g. For the RMS Courses, a comparison shows a 5 times reduction in absorbed power over courses 2 to 5 with the active HMMWV. The active HMMWV has much less sprung mass acceleration, over 4 times reduction at higher speeds, than the passive HMMWV. For the active HMMWV it remains mostly constant at around 0.75 g's to higher speeds while the passive HMMWV shows noticeable increases, at times in excess of 2 g's. Total peak power usage was in the range of 3 kW (RMS and Lane Change Maneuver Courses) and total peak regeneration in the range of 6 kW (RMS Courses) for the active suspension.

INTRODUCTION
This report documents testing of an electromechanical suspension (EMS) on a High Mobility Multi-Purpose Wheeled Vehicle (HMMWV) in Figure 1.

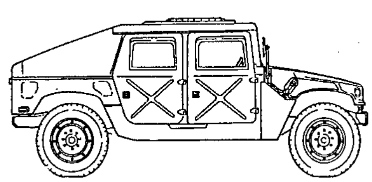


Figure 1 - High Mobility Multi-Purpose Wheeled Vehicle (HMMWV)

HISTORY
Originally, contract DAAE07-93-C-R094 was awarded to the University of Texas-Center for Electromechanics (UT-CEM) to design, fabricate, and test a prototype of an electromechanical (EM) actuator for use as a suspension system component in a future main battle tank. A rotary actuator, similar to the current Abrams M1A1 trailing arm suspension unit, was developed. Leveraging off this development effort to demonstrate the technology on wheeled vehicles, contract DAAE07-95-C-X167 was awarded to UT-CEM to develop a high performance linear actuator for an electromechanical active suspension. The focus in this contract was on the mechanical design and baseline control algorithms. For a final demonstration and refinement of this technology, contract DAAE07-98-C-L020 was awarded to UT-CEM to demonstrate the EMS system on a vehicle--the HMMWV.

Figure 2 depicts the actuator installed into the passive HMMWV suspension with slight modification for the mounting bracket. Figure 3 shows different views of the installed actuator.

FOCUS
The testing documented by this report is from the first of three planned test sessions. Each phase is intended to 1) provide more information for refinement of the control algorithms, 2) prove the technology, and 3) demonstrate the performance gains possible of an electromechanical suspension over a passive one. Testing was held at the U.S. Army Proving Grounds (YPG) in Yuma, Arizona. In attendance were personnel from the U.S. Army Tank-automotive and Armaments Command, Research, Development and Engineering Center (TACOM-TARDEC), the University of Texas-Center for Electromechanics (UT-CEM), and YPG.

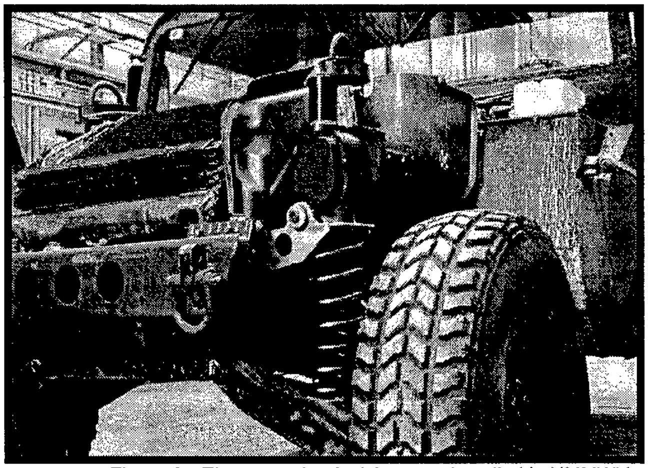


Figure 2 - Electromechanical Actuator installed in HMMWV

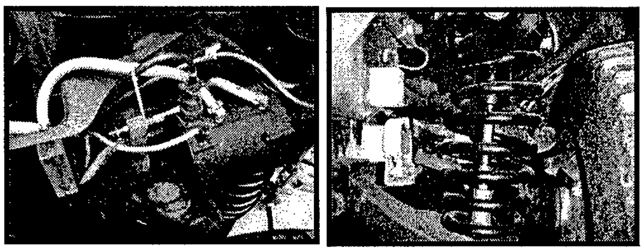


Figure 3 - Installed Actuator Top and Side Views

TEST PLAN

The U.S. Army Tank-automotive and Armaments Command is involved in the development of advanced suspension technology to increase the mobility performance of Army vehicles. The objective of testing is to quantify the actual performance gains in ride quality, shock quality, and maneuverability of the electromechanical active suspension over a passive suspension system. The tests designed to produce these quantities are summarized below with the full description of the test plan included in APPENDIX A.

RIDE

The performance criteria for ride quality is based on absorbed power, a human tolerance limit to vibration, developed by Lee and Pradko (1968), Lins (1969), Lins (1972), Pradko et. al. (1965), Pradko et. al. (1966) and reviewed by Smith et.al. (1978). It is a time average of frequency weighted accelerations received by the driver. To produce the quantity the vehicle is driven over various roughness courses, as shown in Figure 4, at increasing speeds. The filter is applied to the accelerations recorded for each pass and when they reach the limit (6 watts) that speed is recorded as the ride limiting speed. A plot of the ride limiting speed versus roughness is made.

SHOCK

The performance criteria for shock quality is based on a shock limit of 2.5 g's. It is the maximum instantaneous shock acceleration received by the driver. To produce the quantity the vehicle is driven over various half-round bump courses, as shown in Figure 5, at increasing speeds. The accelerations are recorded for each pass and when they reach the limit (2.5 g's) that speed is recorded as the shock limiting speed. A plot of the shock limiting speed versus half-round height is made.

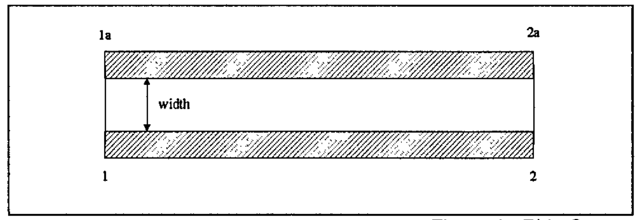


Figure 4 - Ride Course

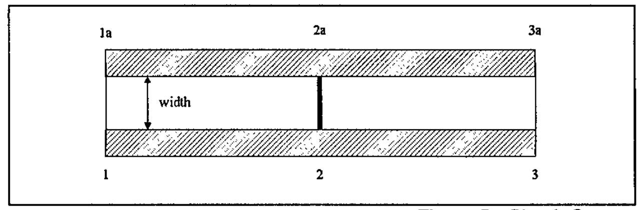


Figure 5 - Shock Course

MANUVERABILITY

The performance criteria for maneuverability is based on a comparative measure for steer angle, roll rate, and lateral acceleration. There is no defined limit, as is the case for ride and shock, so measureable amounts of improvement are the desired objective. To produce the comparisons the vehicle is driven through the lane change and slalom courses with course parameters defined for each run, as shown in Figure 6 and 7, at increasing speeds. The signals are recorded for each pass. A plot of the appropriate signals are made for comparison.

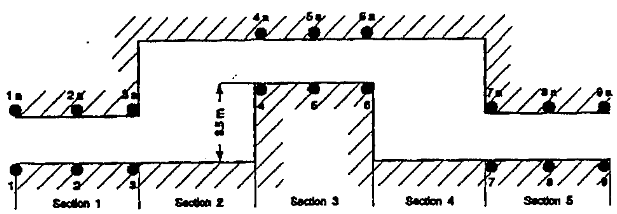


Figure 6 - Lane Change Course

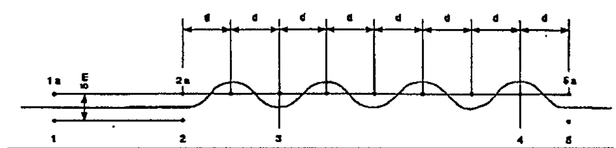


Figure 7 - Slalom Course

RESULTS

The tests conducted to produce the following results were performed on 8-10 November, 1999 at YPG. Preliminary discussions took place to determine instrumentation configuration, data collection issues, sensor placement, data output format, order of testing, and other logistical concerns. The active EMS HMMWV used MATLAB from The MathWorks, Inc. coupled with a dSPACE, Inc. board for suspension control and data acquisition while the passive HMMWV was equipped with a Campbell Scientific, Inc. CR9000 data acquisition system, both sampling at 500 Hz.

It was determined to arrange the order of tests to be 1) Lane Change Maneuver, 2) Constant Step Slalom, 3) RMS Courses, and 4) Half-Round Bumps. This was done to reduce the potential of actuator failure from severe demands on it by starting with the least structurally demanding tests first. In this

phase of testing there were no physical jounce bump stops or bump stop avoidance and damping cancelation algorithms implemented.

Before testing began, the EMS HMMWV was unloaded from the truck it was transported to YPG in and setup for testing was completed. Prior to arrival at the test site, the passive HMMWV (M998) was loaded with 5,900 pounds of dummy weight to match the 7,500 pounds of the EMS HMMWV. Each vehicle, passive and active, were weighed for gross vehicle weight (GVW), front and rear axle, left and right side, and under each wheel. Figures 8 and 9 detail the measurements obtained.

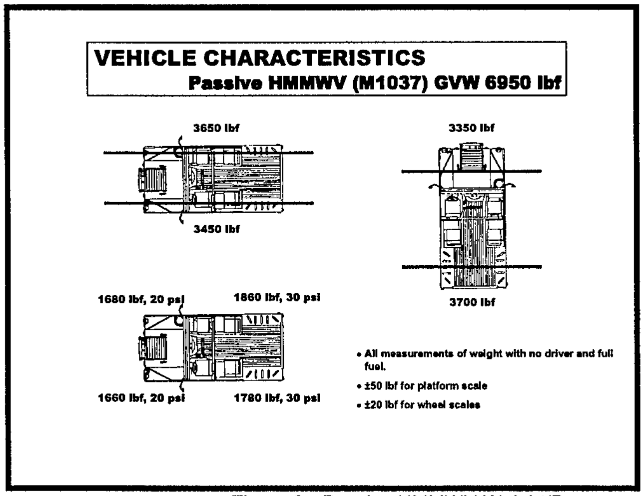


Figure 8 - Passive HMMWV Weight/Pressure

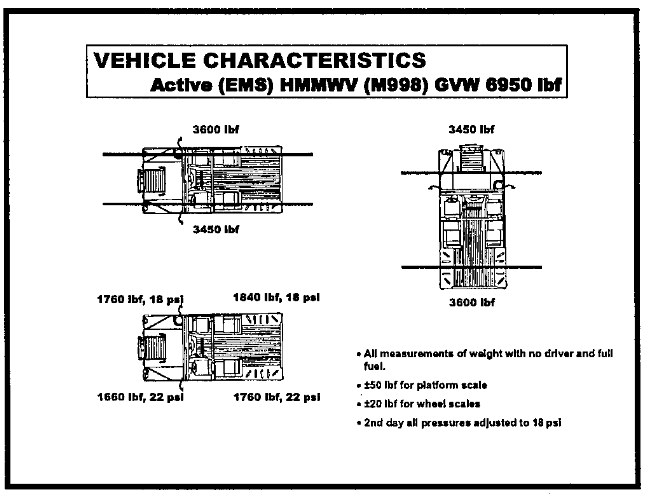


Figure 9 - EMS HMMWV Weight/Pressure

The driver's acceleration sensor for each vehicle was relocated to the frame structure behind the driver's seat for solid support. Modification was made to the mounting of the UT-CEM CG rate sensor to include a foam pad underneath. Yuma Proving Grounds uses this to reduce engine vibration noise picked up by the sensors.

Data signals were extracted from the captured test files by first locating their position within the file and then converting to consistent units for presentation. While single order 16 Hz analog low-pass butterworth filters were used on the EMS HMMWV, no analog low-pass filtering was used on the passive HMMWV. The data plots presented here for both active and passive vehicles are after being extracted and low-pass filtered (16 Hz) in the digital domain. In addition, the passive signals were median filtered with a window of five.

In an effort to present understandable data, the following results have been summarized to representative values or snapshots over each range of speeds or set of courses using maximum and minimum peak values for each run. While not capturing all details, it serves to provide some idea of the performance characteristics discovered. The time lengths of the active and passive signals are different due to slight variations or fluctuations in vehicle speed and data collection cutoff. This technique for presentation of results is thus designed to give an indication of the performance envelope.

LANE CHANGE MANEUVER

The Lane Change Maneuver, see Figure 10, was conducted for the passive HMMWV for both North and South directions starting at 20 MPH and going up to 55 MPH. The Lane Change Maneuver was conducted for the active EMS HMMWV for both North and South directions starting at 20 MPH and going up to 55 MPH. Two practice runs were taken by the driver to get a good "feel" for the new EM suspension. An actuator fault occurred on one of the runs. Two runs for the passive HMMWV were repeated due to missing data for 30 and 35 MPH.

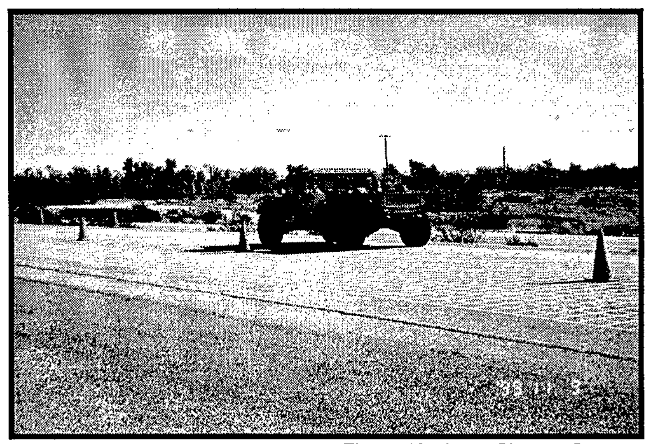


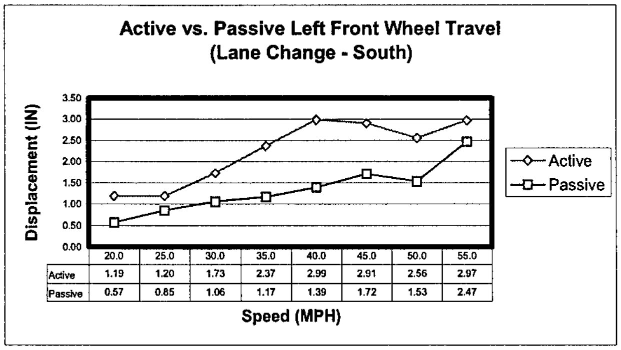
Figure 10 - Lane Change Course

Due to sensor cost and availability both HMMWV's did not maintain the same sensor suite. In particular, the EMS HMMWV contained only one rate sensor at the CG that was to be switched between roll and pitch measurements depending upon which test, Lane Change or RMS Course, was being conducted. During Lane Change testing the sensor was not switched from pitch sensing to roll sensing and thus all the "roll" data for the Lane Change on the EMS HMMWV is pitch data.

For common performance comparisons wheel travel, sprung acceleration, and CG lateral acceleration were chosen to best compare the performance distinctions between passive and active suspension systems for the Lane Change Maneuver. Due to differences in the sensor suites, additional signals were included for the active (power) and passive (roll rate, yaw rate, and steer angle) that still provide important and insightful information from the tests.

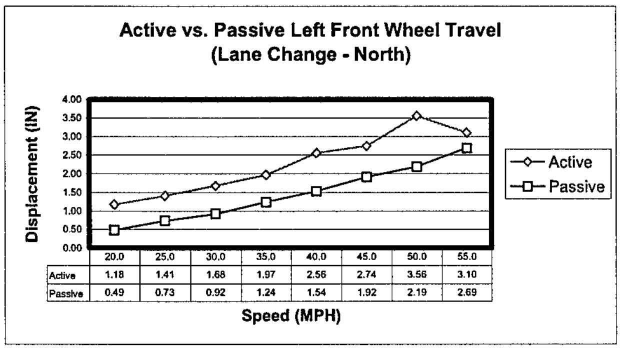
Active and Passive Wheel Travel

Figures 11-18 show active and passive wheel travel for each wheel station, both North and South.



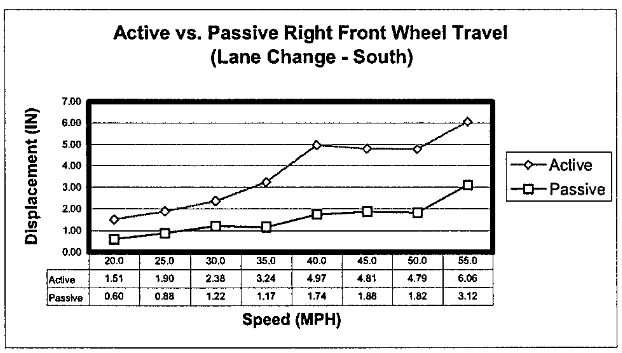
	20.0	25.0	30.0	35.0	40.0	45.0	50.0	55.0
Active	1.19	1.20	1.73	2.37	2.99	2.91	2.56	2.97
Passive	0.57	0.85	1.06	1.17	1.39	1.72	1.53	2.47

Figure 11 - Left Front Wheel Travel (South)



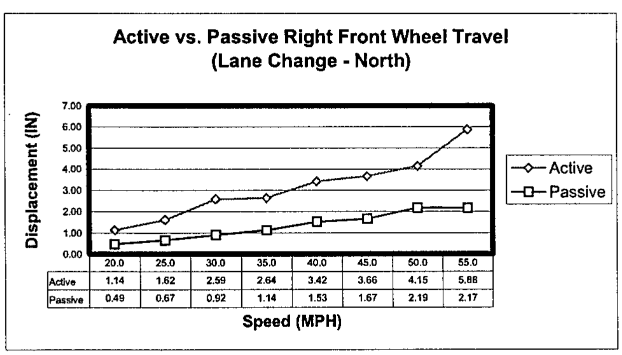
	20.0	25.0	30.0	35.0	40.0	45.0	50.0	55.0
Active	1.18	1.41	1.68	1.97	2.56	2.74	3.56	3.10
Passive	0.49	0.73	0.92	1.24	1.54	1.92	2.19	2.69

Figure 12 - Left Front Wheel Travel (North)



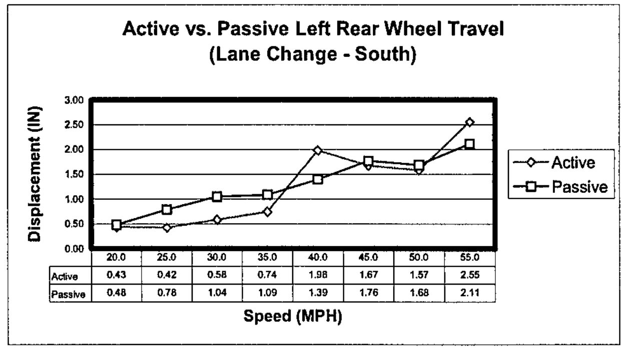
	20.0	25.0	30.0	35.0	40.0	45.0	50.0	55.0
Active	1.51	1.90	2.38	3.24	4.97	4.81	4.79	6.06
Passive	0.60	0.88	1.22	1.17	1.74	1.88	1.82	3.12

Figure 13 - Right Front Wheel Travel (South)



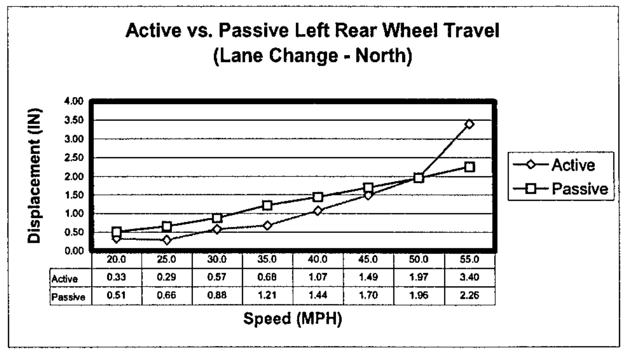
	20.0	25.0	30.0	35.0	40.0	45.0	50.0	55.0
Active	1.14	1.62	2.59	2.64	3.42	3.66	4.15	5.88
Passive	0.49	0.67	0.92	1.14	1.53	1.67	2.19	2.17

Figure 14 - Right Front Wheel Travel (North)



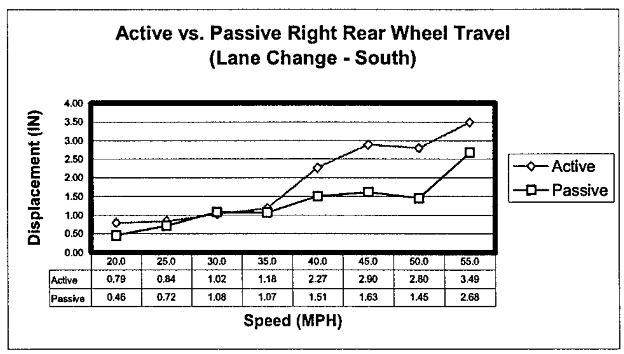
	20.0	25.0	30.0	35.0	40.0	45.0	50.0	55.0
Active	0.43	0.42	0.58	0.74	1.98	1.67	1.57	2.55
Passive	0.48	0.78	1.04	1.09	1.39	1.76	1.68	2.11

Figure 15 - Left Rear Wheel Travel (South)



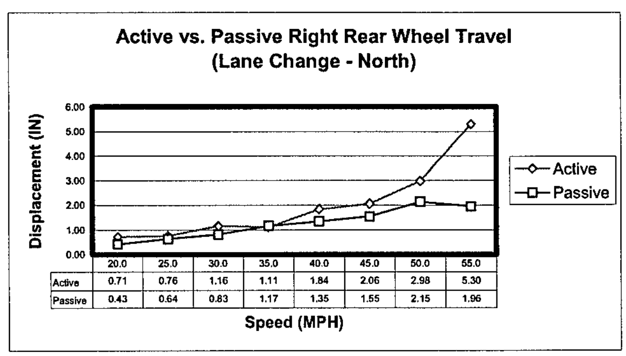
	20.0	25.0	30.0	35.0	40.0	45.0	50.0	55.0
Active	0.33	0.29	0.57	0.68	1.07	1.49	1.97	3.40
Passive	0.51	0.66	0.88	1.21	1.44	1.70	1.96	2.26

Figure 16 - Left Rear Wheel Travel (North)



	20.0	25.0	30.0	35.0	40.0	45.0	50.0	55.0
Active	0.79	0.84	1.02	1.18	2.27	2.90	2.80	3.49
Passive	0.46	0.72	1.08	1.07	1.51	1.63	1.45	2.68

Figure 17 - Right Rear Wheel Travel (South)

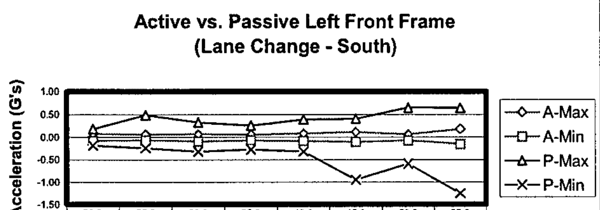


	20.0	25.0	30.0	35.0	40.0	45.0	50.0	55.0
Active	0.71	0.76	1.16	1.11	1.84	2.06	2.98	5.30
Passive	0.43	0.64	0.83	1.17	1.35	1.55	2.15	1.96

Figure 18 - Right Rear Wheel Travel (North)

Active and Passive Sprung Mass Acceleration

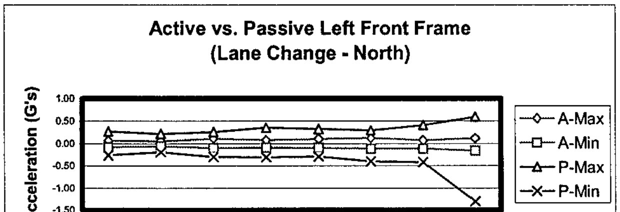
Figures 19 - 26 show active and passive sprung mass acceleration for each wheel station, both North and South.



	20.0	25.0	30.0	35.0	40.0	45.0	50.0	55.0
A-Max	0.08	0.06	0.07	0.06	0.08	0.11	0.07	0.18
A-Min	-0.08	-0.06	-0.09	-0.07	-0.08	-0.10	-0.07	-0.15
P-Max	0.18	0.49	0.33	0.26	0.39	0.41	0.65	0.65
P-Min	-0.18	-0.24	-0.32	-0.27	-0.32	-0.94	-0.59	-1.24

Speed (MPH)

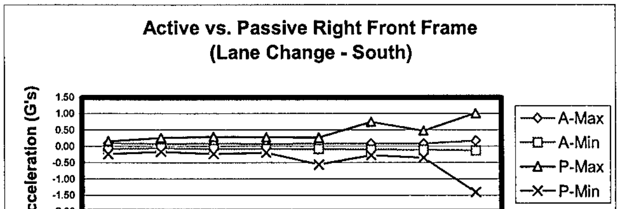
Figure 19 - Left Front Frame Acceleration (South)



	20.0	25.0	30.0	35.0	40.0	45.0	50.0	55.0
A-Max	0.06	0.06	0.11	0.08	0.11	0.13	0.07	0.12
A-Min	-0.08	-0.06	-0.10	-0.09	-0.09	-0.11	-0.11	-0.16
P-Max	0.27	0.22	0.26	0.36	0.33	0.29	0.41	0.60
P-Min	-0.26	-0.19	-0.30	-0.30	-0.29	-0.40	-0.42	-1.31

Speed (MPH)

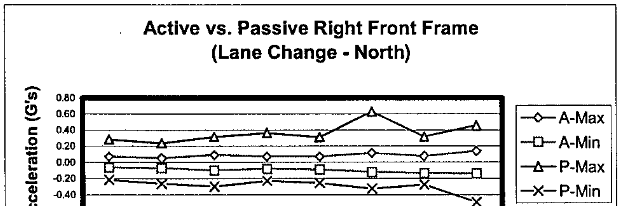
Figure 20 - Left Front Frame Acceleration (North)



	20.0	25.0	30.0	35.0	40.0	45.0	50.0	55.0
A-Max	0.10	0.06	0.08	0.07	0.08	0.08	0.08	0.17
A-Min	-0.07	-0.05	-0.08	-0.08	-0.08	-0.10	-0.11	-0.13
P-Max	0.15	0.26	0.29	0.28	0.26	0.75	0.47	1.01
P-Min	-0.24	-0.17	-0.23	-0.19	-0.56	-0.27	-0.35	-1.41

Speed (MPH)

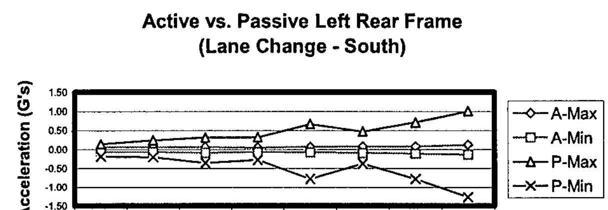
Figure 21 - Right Front Frame Acceleration (South)



	20.0	25.0	30.0	35.0	40.0	45.0	50.0	55.0
A-Max	0.07	0.05	0.09	0.07	0.07	0.12	0.08	0.14
A-Min	-0.06	-0.07	-0.10	-0.08	-0.09	-0.12	-0.14	-0.14
P-Max	0.28	0.24	0.31	0.36	0.31	0.63	0.32	0.45
P-Min	-0.21	-0.26	-0.30	-0.23	-0.26	-0.33	-0.28	-0.49

Speed (MPH)

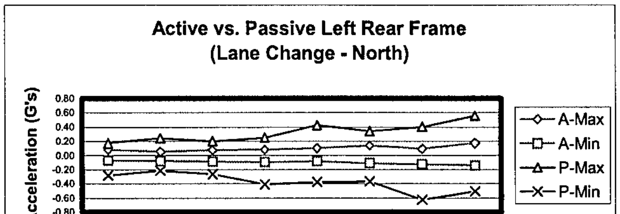
Figure 22 - Right Front Frame Acceleration (North)



	20.0	25.0	30.0	35.0	40.0	45.0	50.0	55.0
A-Max	0.07	0.07	0.07	0.06	0.08	0.09	0.09	0.13
A-Min	-0.06	-0.07	-0.09	-0.07	-0.08	-0.09	-0.11	-0.13
P-Max	0.14	0.24	0.32	0.33	0.67	0.48	0.72	1.01
P-Min	-0.18	-0.20	-0.35	-0.27	-0.78	-0.37	-0.78	-1.26

Speed (MPH)

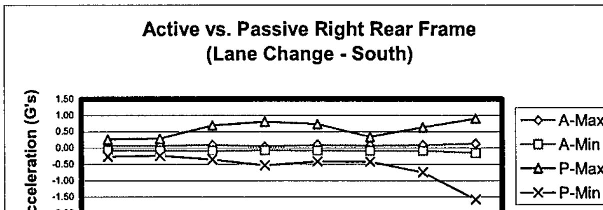
Figure 23 - Left Rear Frame Acceleration (South)



	20.0	25.0	30.0	35.0	40.0	45.0	50.0	55.0
A-Max	0.08	0.05	0.08	0.08	0.10	0.14	0.09	0.17
A-Min	-0.07	-0.08	-0.09	-0.09	-0.08	-0.11	-0.13	-0.14
P-Max	0.17	0.24	0.20	0.25	0.43	0.34	0.40	0.56
P-Min	-0.28	-0.22	-0.26	-0.41	-0.37	-0.37	-0.63	-0.51

Speed (MPH)

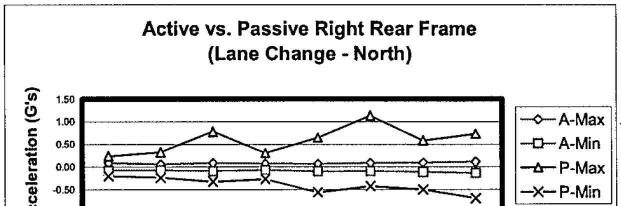
Figure 24 - Left Rear Frame Acceleration (North)



	20.0	25.0	30.0	35.0	40.0	45.0	50.0	55.0
A-Max	0.07	0.07	0.10	0.06	0.09	0.08	0.09	0.14
A-Min	-0.07	-0.07	-0.08	-0.07	-0.08	-0.08	-0.09	-0.15
P-Max	0.26	0.28	0.70	0.81	0.73	0.33	0.63	0.89
P-Min	-0.26	-0.24	-0.35	-0.53	-0.41	-0.42	-0.74	-1.58

Speed (MPH)

Figure 25 - Right Rear Frame Acceleration (South)



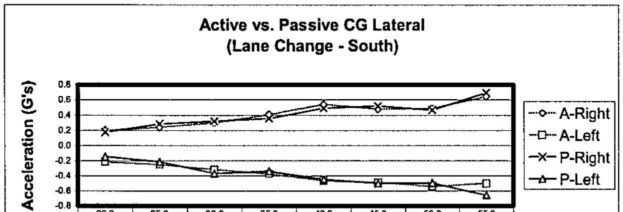
	20.0	25.0	30.0	35.0	40.0	45.0	50.0	55.0
A-Max	0.09	0.06	0.08	0.08	0.07	0.08	0.09	0.11
A-Min	-0.07	-0.07	-0.08	-0.06	-0.09	-0.09	-0.12	-0.14
P-Max	0.24	0.33	0.78	0.31	0.64	1.14	0.59	0.73
P-Min	-0.20	-0.24	-0.32	-0.27	-0.56	-0.42	-0.50	-0.69

Speed (MPH)

Figure 26 - Right Rear Frame Acceleration (North)

Active and Passive CG Lateral Acceleration

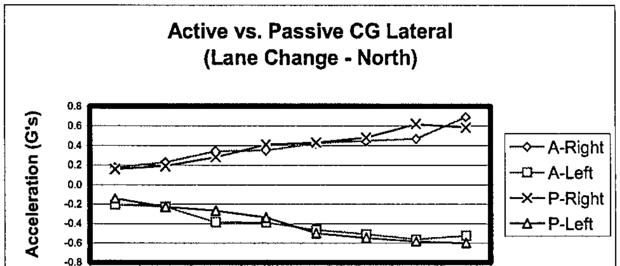
Figures 27-28 show active and passive CG lateral acceleration for both North and South.



	20.0	25.0	30.0	35.0	40.0	45.0	50.0	55.0
A-Right	0.20	0.24	0.30	0.41	0.54	0.48	0.49	0.64
A-Left	-0.21	-0.25	-0.32	-0.38	-0.47	-0.49	-0.54	-0.50
P-Right	0.18	0.28	0.32	0.36	0.49	0.52	0.47	0.70
P-Left	-0.15	-0.22	-0.37	-0.34	-0.45	-0.50	-0.49	-0.66

Speed (MPH)

Figure 27 - CG Lateral Acceleration (South)



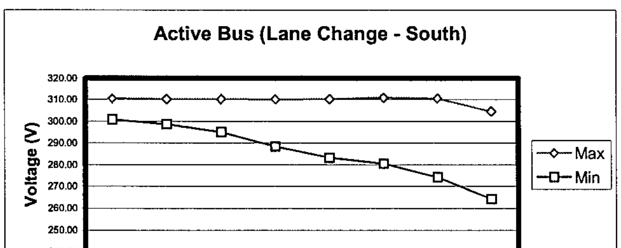
	20.0	25.0	30.0	35.0	40.0	45.0	50.0	55.0
A-Right	0.18	0.23	0.34	0.35	0.42	0.45	0.47	0.89
A-Left	-0.20	-0.23	-0.38	-0.39	-0.46	-0.51	-0.56	-0.52
P-Right	0.16	0.19	0.28	0.41	0.43	0.48	0.62	0.58
P-Left	-0.14	-0.23	-0.26	-0.34	-0.50	-0.54	-0.58	-0.60

Speed (MPH)

Figure 28 - CG Lateral Acceleration (North)

Active Power

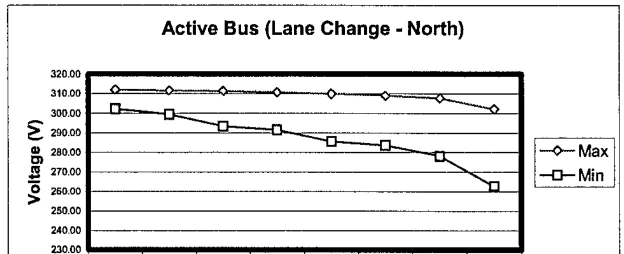
Figures 29 - 36 show (servo amplifier) bus voltage, rectifier current, Pulse Width Modulated (PWM) current, and power consumption, both North and South. Due to the drifting of the hall-effect current sensors, the PWM current was offset by its minimum value so that it was never below zero (no regeneration) to obtain an estimate of the total peak current and total peak power consumption of the EMS.



	20.0	25.0	30.0	35.0	40.0	45.0	50.0	55.0
Max	310.61	310.33	310.29	310.18	310.28	310.98	310.67	304.63
Min	300.94	298.71	295.05	288.38	283.22	280.48	274.18	264.33

Speed (MPH)

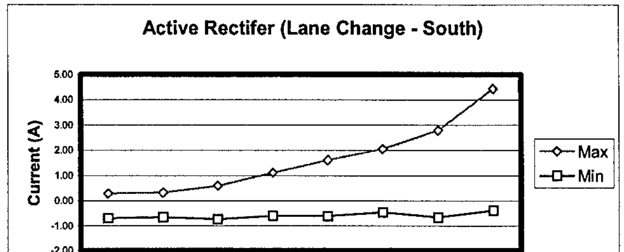
Figure 29 - Bus Voltage (South)



	20.0	25.0	30.0	35.0	40.0	45.0	50.0	55.0
Max	312.02	311.63	311.39	310.83	309.94	309.01	307.81	302.19
Min	302.34	299.46	293.44	291.57	285.69	283.65	278.13	262.79

Speed (MPH)

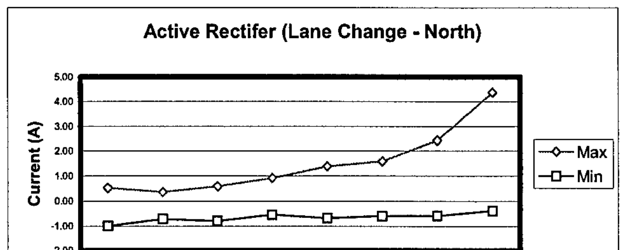
Figure 30 - Bus Voltage (North)



	20.0	25.0	30.0	35.0	40.0	45.0	50.0	55.0
Max	0.29	0.32	0.60	1.11	1.62	2.06	2.79	4.45
Min	-0.70	-0.66	-0.74	-0.60	-0.61	-0.46	-0.66	-0.38

Speed (MPH)

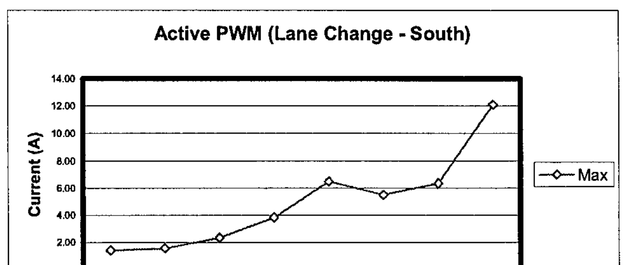
Figure 31 - Rectifier Current (South)



	20.0	25.0	30.0	35.0	40.0	45.0	50.0	55.0
Max	0.53	0.36	0.59	0.92	1.39	1.60	2.43	4.38
Min	-1.00	-0.71	-0.78	-0.54	-0.68	-0.59	-0.58	-0.38

Speed (MPH)

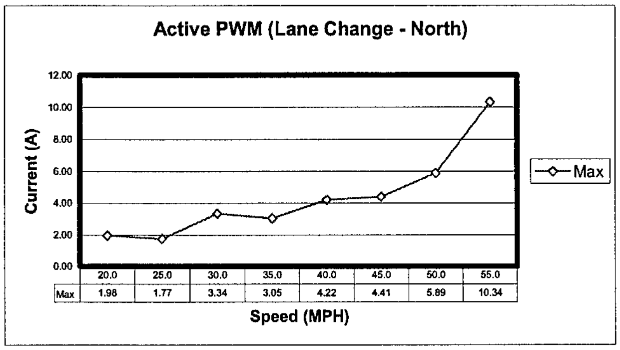
Figure 32 - Rectifier Current (North)



	20.0	25.0	30.0	35.0	40.0	45.0	50.0	55.0
Max	1.41	1.57	2.35	3.85	6.51	5.52	6.36	12.12

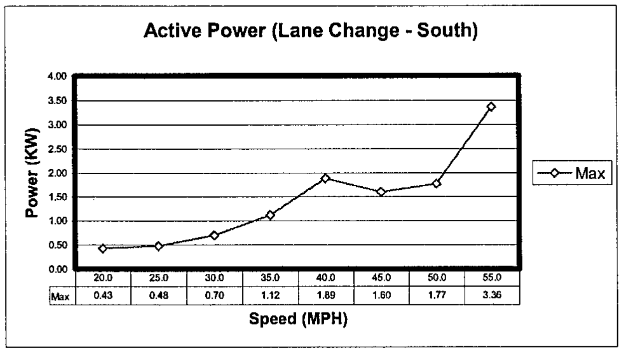
Speed (MPH)

Figure 33 - PWM Current (South)



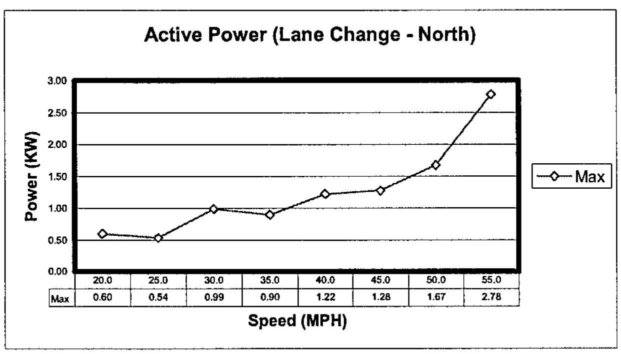
	20.0	25.0	30.0	35.0	40.0	45.0	50.0	55.0
Max	1.98	1.77	3.34	3.05	4.22	4.41	5.89	10.34

Figure 34 - PWM Current (North)



	20.0	25.0	30.0	35.0	40.0	45.0	50.0	55.0
Max	0.43	0.48	0.70	1.12	1.89	1.60	1.77	3.36

Figure 35 - Power (South)

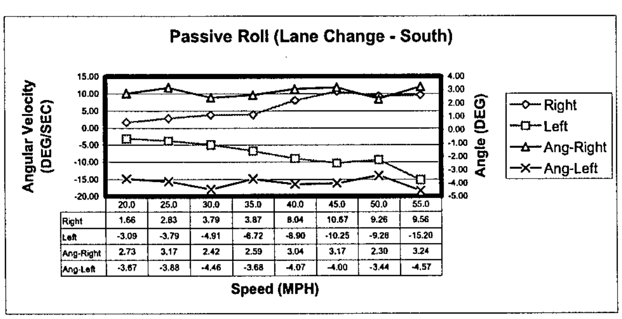


	20.0	25.0	30.0	35.0	40.0	45.0	50.0	55.0
Max	0.60	0.54	0.99	0.90	1.22	1.28	1.67	2.78

Figure 36 - Power (North)

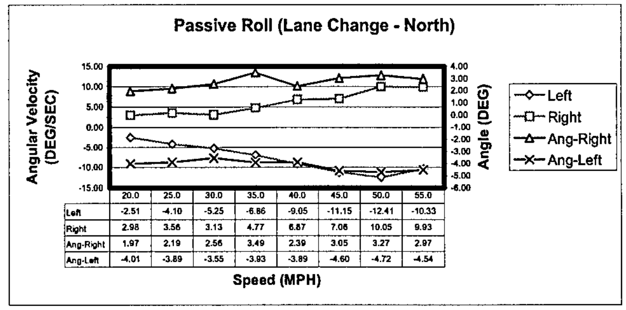
Passive Roll

Figures 37 - 40 show passive roll rate, both North and South.



	20.0	25.0	30.0	35.0	40.0	45.0	50.0	55.0
Right	1.66	2.83	3.79	3.87	8.04	10.67	9.26	9.56
Left	-3.09	-3.79	-4.91	-6.72	-8.90	-10.25	-9.28	-15.20
Ang-Right	2.73	3.17	2.42	2.59	3.04	3.17	2.30	3.24
Ang-Left	-3.67	-3.88	-4.46	-3.68	-4.07	-4.00	-3.44	-4.57

Figure 37 - Roll Rate (South)

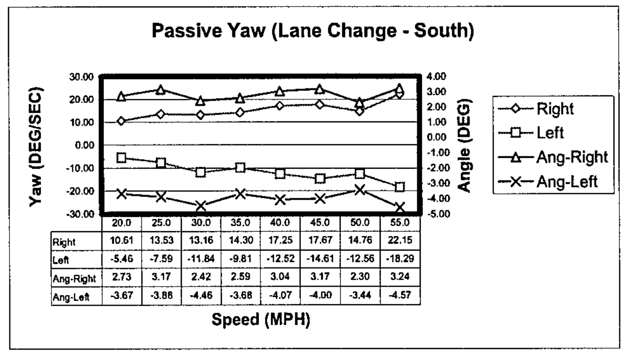


	20.0	25.0	30.0	35.0	40.0	45.0	50.0	55.0
Left	-2.51	-4.10	-5.25	-6.86	-9.05	-11.15	-12.41	-10.33
Right	2.98	3.56	3.13	4.77	6.87	7.06	10.05	9.93
Ang-Right	1.97	2.19	2.56	3.49	2.39	3.05	3.27	2.97
Ang-Left	-4.01	-3.89	-3.55	-3.93	-3.89	-4.60	-4.72	-4.54

Figure 38 - Roll Rate (North)

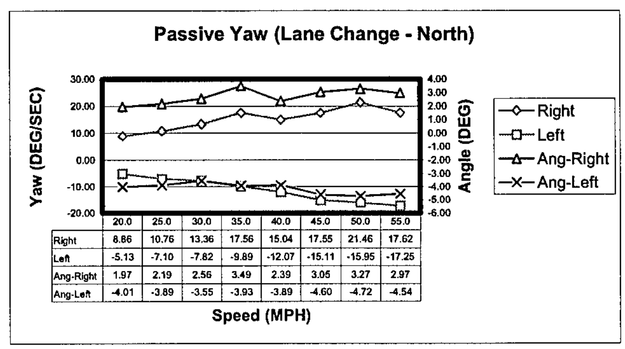
Passive Yaw Rate and Steer Angle

Figures 39 - 40 show passive yaw rate and steer angle, both North and South.



	20.0	25.0	30.0	35.0	40.0	45.0	50.0	55.0
Right	10.61	13.53	13.16	14.30	17.25	17.67	14.76	22.15
Left	-5.46	-7.59	-11.84	-9.81	-12.52	-14.61	-12.56	-18.29
Ang-Right	2.73	3.17	2.42	2.59	3.04	3.17	2.30	3.24
Ang-Left	-3.67	-3.88	-4.46	-3.68	-4.07	-4.00	-3.44	-4.57

Figure 39 - Yaw Rate and Steer Angle (South)



	20.0	25.0	30.0	35.0	40.0	45.0	50.0	55.0
Right	8.86	10.76	13.36	17.56	15.04	17.55	21.46	17.62
Left	-5.13	-7.10	-7.82	-9.89	-12.07	-15.11	-15.95	-17.25
Ang-Right	1.97	2.19	2.56	3.49	2.39	3.05	3.27	2.97
Ang-Left	-4.01	-3.89	-3.55	-3.93	-3.89	-4.60	-4.72	-4.54

Figure 40 - Yaw Rate and Steer Angle (South)

CONSTANT STEP SLALOM

The Constant Step Slalom was initiated for the passive HMMWV with a cone spacing of 32.8 feet at 5, 10, and 15 MPH. No data was collected at the 15 MPH speed due to the difficulty of the driver to maintain a constant speed with so close of cone spacing. Some practice runs were taken with a cone spacing of 65 feet which allowed the vehicle to maintain a higher speed. The Constant Step Slalom was conducted for the EMS HMMWV at 5 MPH. A resolver error occurred. At this point the EMS HMMWV was taken back to the truck pad for analysis and repair of the actuator. Due to uncertainty regarding (available testing) time, status of the actuator, and type of test importance testing of the Constant Step Slalom was halted. No results on this test are reported because not enough data was taken to make a solid comparison.

RMS COURSES

The Ride Quality or RMS Course test, see Figure 41, was conducted with the passive HMMWV over course 2 (1.3" RMS, 1000 feet, rougher at far end-North) from 5 to 35 MPH. Course 2 was more like a shock course with ruts due to its construction and less like natural roughness. The RMS Course test was conducted on the EMS HMMWV, after fixing the resolver error from the Constant Step Slalom test, over course 2 from 5 to 25 MPH. On the 25 MPH run testing was stopped 3/4 of the way through due to a torque slip problem with one of the actuators. The vehicle was taken back for repair. Testing proceeded with the passive HMMWV over course 3 (1.5" RMS, 1000 feet, more natural like terrain) from 5 MPH to 25 MPH.

Due to concern regarding the actuator malfunctioning again testing (EMS HMMWV) began at lower speeds alternating between course 3 (1.5" RMS), 4 (2.0" RMS), and 5 (3.4" RMS) to get as much data as possible. The speed increment was reduced to 2.5 MPH instead of 5 MPH and analysis of the suspension was done after each run to ensure the actuator was operating in a safe region. Data was collected in an alternating sequence for course 3 for 5 to 35 MPH, course 4 for 5 to 20 MPH, and course 5 for 5 MPH. On course 3 at 35 MPH the test run was aborted due to a control problem in the front left sensor which was thought to be due to faulty sensor data. The EMS HMMWV was then retired for session 1 testing back to the truck pad to be packed up and returned to UT-CEM for analysis and tuning. The passive HMMWV was then run through course 4 at 5 to 20 MPH and course 5 at 5 and 10 MPH.

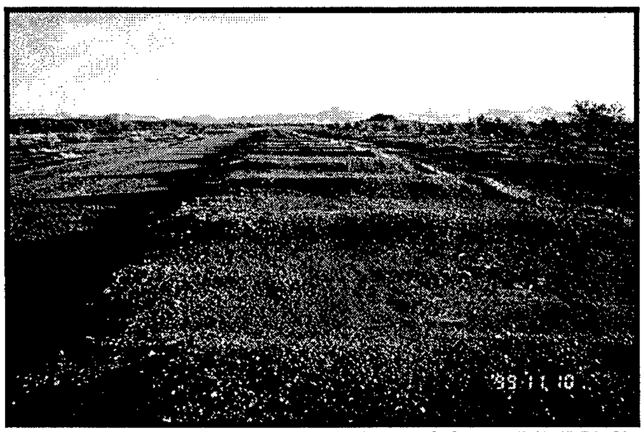


Figure 41 - RMS Course 5 (3.4" RMS)

For common performance comparisons absorbed power (ride quality), wheel travel, sprung mass acceleration, unsprung mass (wheel) acceleration, and pitch rate were chosen to best compare the performance distinctions between passive and active suspension systems for the RMS Courses test. With the exception of absorbed power, all signals are from Course 3 which provided the only complete set of data. However, absorbed power was calculated for all RMS Courses and presented to give some basis to estimate what is currently possible.

Due to differences in the sensor suites, additional signals were included for the active (power) and passive (roll rate, yaw rate, and steer angle) that still provide important and insightful information from the tests.

Active and Passive Absorbed Power

Figures 42 - 45 show active and passive absorbed power for courses 2 to 5 and Figure 46 shows ride limiting speeds over the whole range of RMS Courses tested.

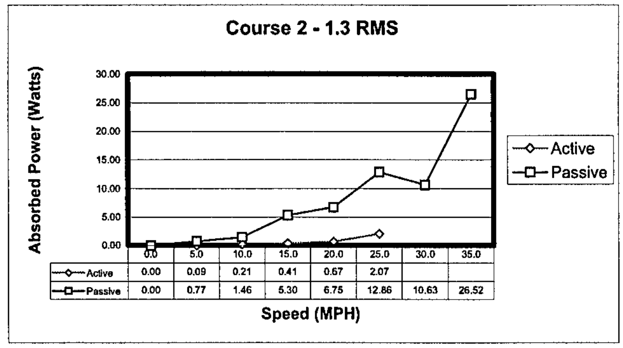


Figure 42 - Absorbed Power Course 2

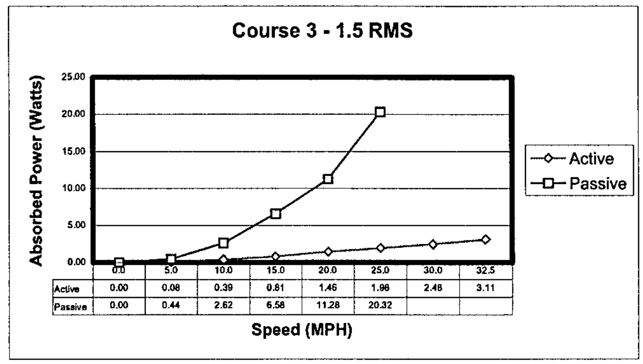


Figure 43 - Absorbed Power Course 3

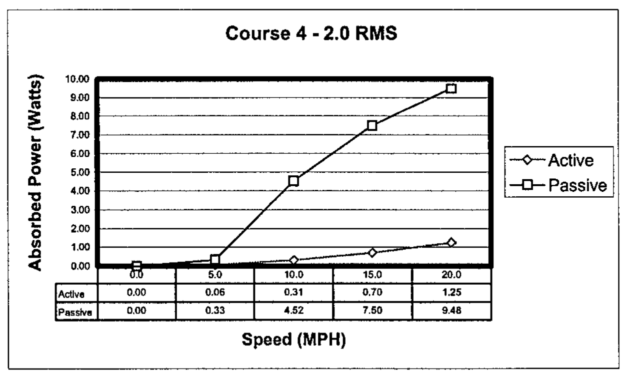


Figure 44 - Absorbed Power Course 4

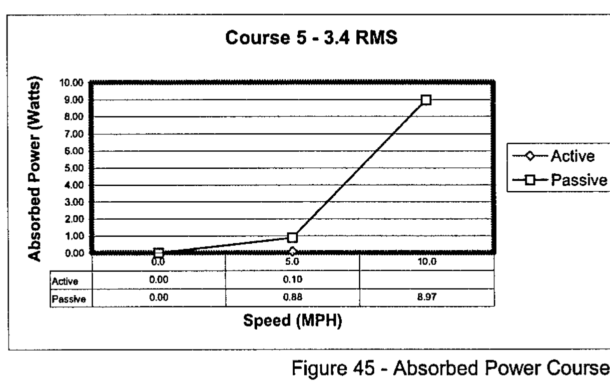
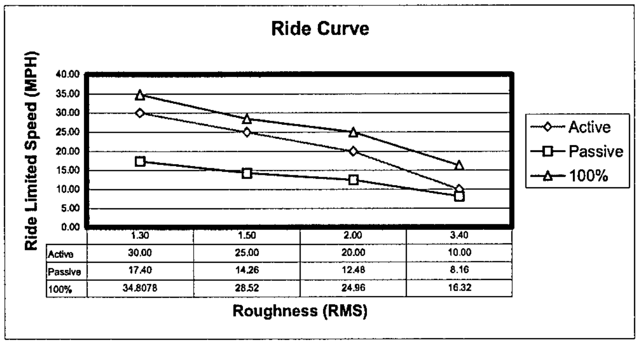


Figure 45 - Absorbed Power Course 5

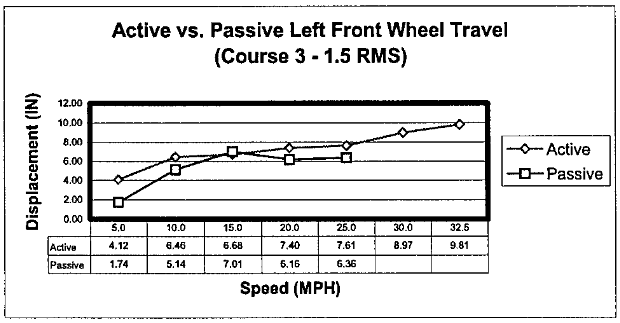


	1.30	1.50	2.00	3.40
Active	30.00	25.00	20.00	10.00
Passive	17.40	14.26	12.48	8.16
100%	34.8078	28.52	24.96	16.32

Figure 46 - Ride Quality/Limiting Speed vs. RMS (estimated)

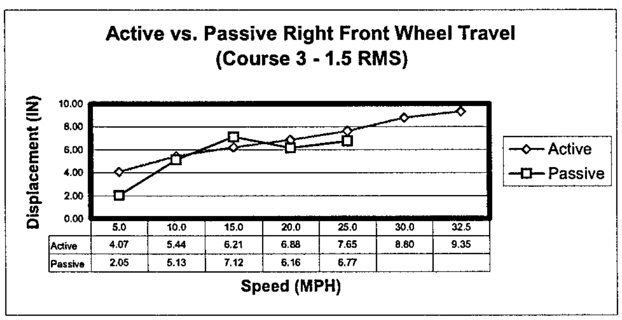
Active and Passive Wheel Travel

Figures 47 - 50 show active and passive wheel travel for each wheel station.



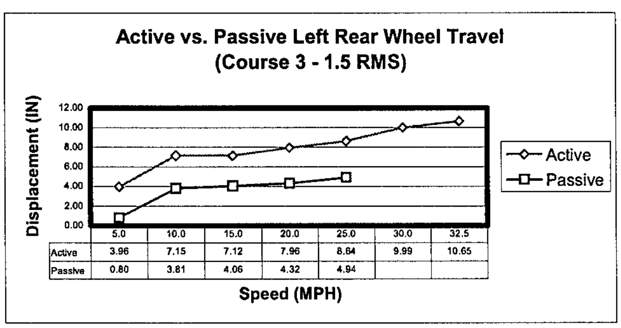
	5.0	10.0	15.0	20.0	25.0	30.0	32.5
Active	4.12	6.46	6.68	7.40	7.61	8.97	9.81
Passive	1.74	5.14	7.01	6.16	6.36		

Figure 47 - Left Front Wheel Travel (Course 3)



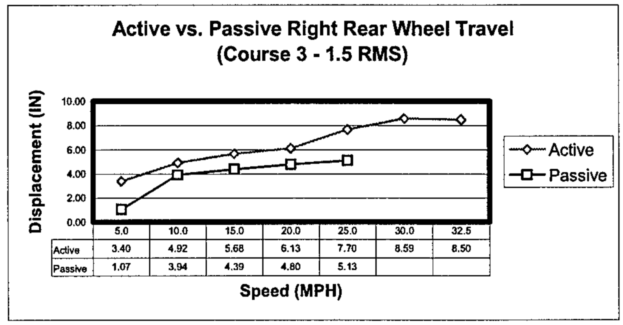
	5.0	10.0	15.0	20.0	25.0	30.0	32.5
Active	4.07	5.44	6.21	6.88	7.65	8.80	9.35
Passive	2.05	5.13	7.12	6.16	6.77		

Figure 48 - Right Front Wheel Travel (Course 3)



	5.0	10.0	15.0	20.0	25.0	30.0	32.5
Active	3.96	7.15	7.12	7.96	8.64	9.99	10.65
Passive	0.80	3.81	4.06	4.32	4.94		

Figure 49 - Left Rear Wheel Travel (Course 3)

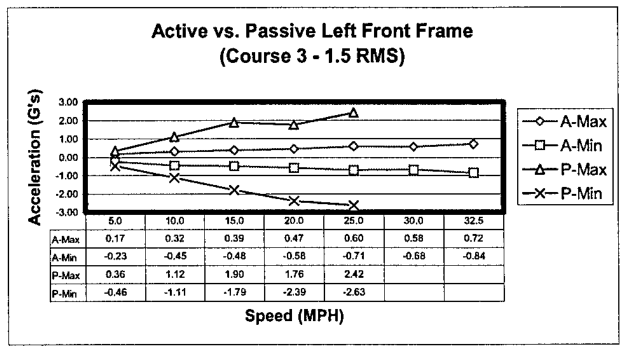


	5.0	10.0	15.0	20.0	25.0	30.0	32.5
Active	3.40	4.92	5.68	6.13	7.70	8.59	8.50
Passive	1.07	3.94	4.39	4.80	5.13		

Figure 50 - Right Rear Wheel Travel (Course 3)

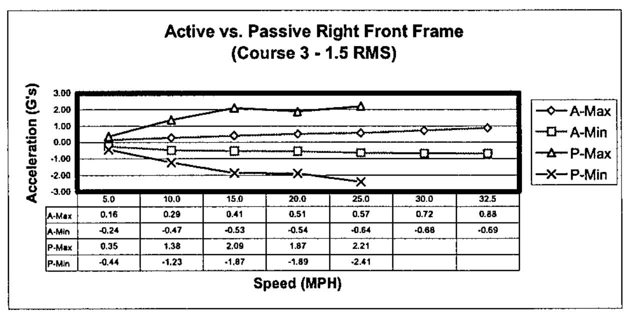
Active and Passive Sprung Mass Acceleration

Figures 51 - 54 show active and passive sprung mass acceleration for each wheel station.



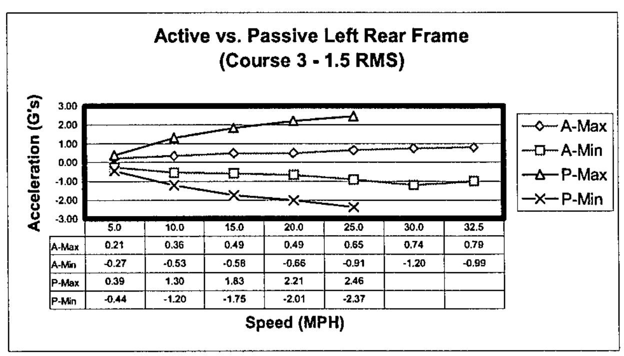
	5.0	10.0	15.0	20.0	25.0	30.0	32.5
A-Max	0.17	0.32	0.39	0.47	0.60	0.58	0.72
A-Min	-0.23	-0.45	-0.48	-0.58	-0.71	-0.68	-0.84
P-Max	0.36	1.12	1.90	1.76	2.42		
P-Min	-0.46	-1.11	-1.79	-2.39	-2.63		

Figure 51 - Left Front Frame Acceleration (Course 3)



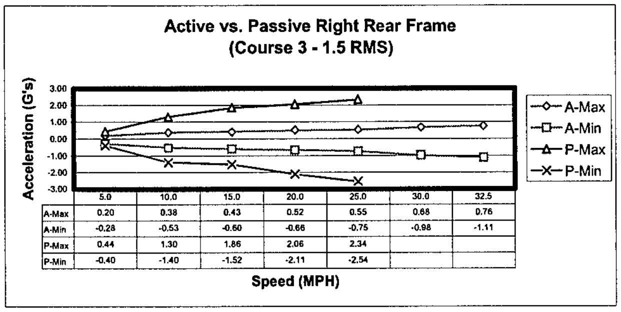
	5.0	10.0	15.0	20.0	25.0	30.0	32.5
A-Max	0.16	0.29	0.41	0.51	0.57	0.72	0.88
A-Min	-0.24	-0.47	-0.53	-0.54	-0.64	-0.68	-0.69
P-Max	0.35	1.38	2.09	1.87	2.21		
P-Min	-0.44	-1.23	-1.87	-1.89	-2.41		

Figure 52- Right Front Frame Acceleration (Course 3)



	5.0	10.0	15.0	20.0	25.0	30.0	32.5
A-Max	0.21	0.36	0.49	0.49	0.65	0.74	0.79
A-Min	-0.27	-0.53	-0.58	-0.66	-0.91	-1.20	-0.99
P-Max	0.39	1.30	1.83	2.21	2.46		
P-Min	-0.44	-1.20	-1.75	-2.01	-2.37		

Figure 53 - Left Rear Frame Acceleration (Course 3)

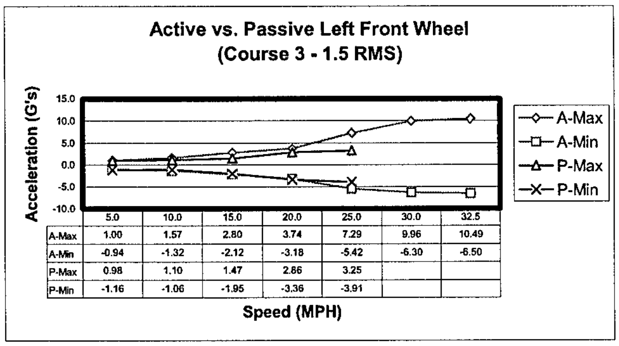


	5.0	10.0	15.0	20.0	25.0	30.0	32.5
A-Max	0.20	0.38	0.43	0.52	0.55	0.68	0.76
A-Min	-0.28	-0.53	-0.60	-0.66	-0.75	-0.98	-1.11
P-Max	0.44	1.30	1.86	2.06	2.34		
P-Min	-0.40	-1.40	-1.52	-2.11	-2.54		

Figure 54 - Right Rear Frame Acceleration (Course 3)

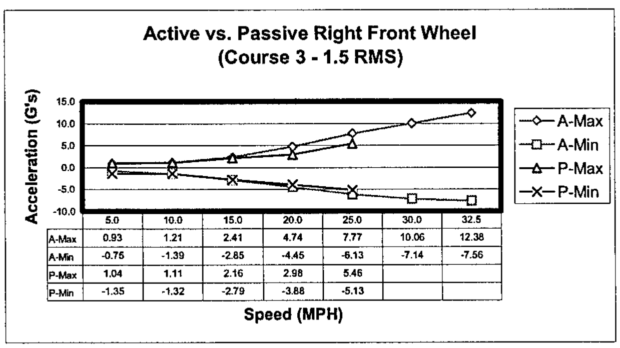
Active and Passive Unsprung Mass Acceleration

Figures 55 - 58 show active and passive unsprung mass acceleration for each wheel station.



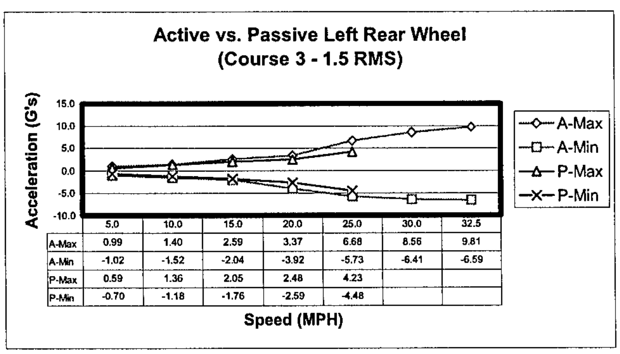
	5.0	10.0	15.0	20.0	25.0	30.0	32.5
A-Max	1.00	1.57	2.80	3.74	7.29	9.96	10.49
A-Min	-0.94	-1.32	-2.12	-3.18	-5.42	-6.30	-6.50
P-Max	0.98	1.10	1.47	2.86	3.25		
P-Min	-1.16	-1.06	-1.95	-3.36	-3.91		

Figure 55 - Left Front Wheel Acceleration (Course 3)



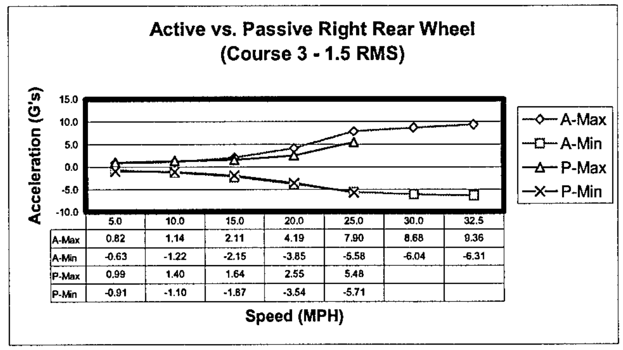
	5.0	10.0	15.0	20.0	25.0	30.0	32.5
A-Max	0.93	1.21	2.41	4.74	7.77	10.06	12.38
A-Min	-0.75	-1.39	-2.85	-4.45	-6.13	-7.14	-7.56
P-Max	1.04	1.11	2.16	2.98	5.46		
P-Min	-1.35	-1.32	-2.79	-3.88	-5.13		

Figure 56 - Right Front Wheel Acceleration (Course 3)



	5.0	10.0	15.0	20.0	25.0	30.0	32.5
A-Max	0.99	1.40	2.59	3.37	6.68	8.56	9.81
A-Min	-1.02	-1.52	-2.04	-3.92	-5.73	-6.41	-6.59
P-Max	0.59	1.36	2.05	2.48	4.23		
P-Min	-0.70	-1.18	-1.76	-2.59	-4.48		

Figure 57 - Left Rear Wheel Acceleration (Course 3)

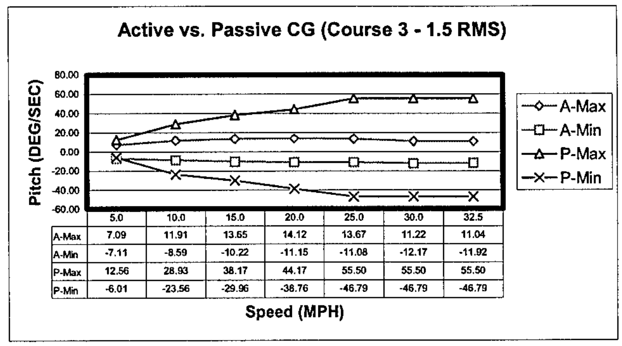


	5.0	10.0	15.0	20.0	25.0	30.0	32.5
A-Max	0.82	1.14	2.11	4.19	7.90	8.68	9.36
A-Min	-0.63	-1.22	-2.15	-3.85	-5.58	-6.04	-6.31
P-Max	0.99	1.40	1.64	2.55	5.48		
P-Min	-0.91	-1.10	-1.87	-3.54	-5.71		

Figure 58 - Right Rear Wheel Acceleration (Course 3)

Active and Passive Pitch Rate

Figure 59 shows active and passive CG pitch rate.

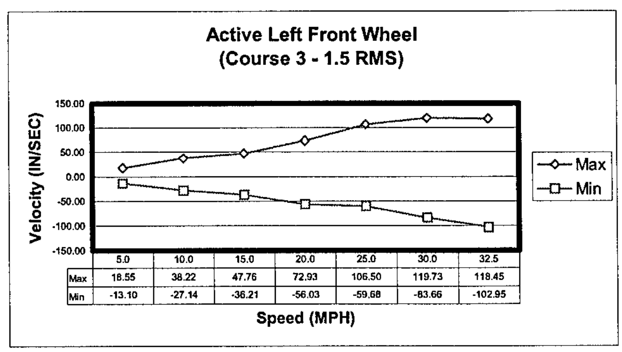


	5.0	10.0	15.0	20.0	25.0	30.0	32.5
A-Max	7.09	11.91	13.65	14.12	13.67	11.22	11.04
A-Min	-7.11	-8.59	-10.22	-11.15	-11.08	-12.17	-11.92
P-Max	12.56	28.93	38.17	44.17	55.50	55.50	55.50
P-Min	-6.01	-23.56	-29.96	-38.76	-46.79	-46.79	-46.79

Figure 59 - CG Pitch Rate (Course 3)

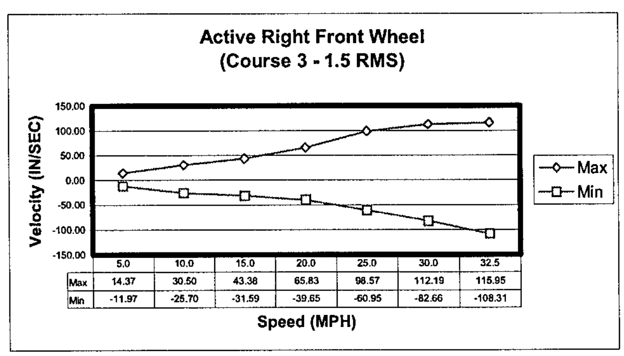
Active Wheel Velocity

Figures 60 - 63 show active wheel velocity for each wheel station.



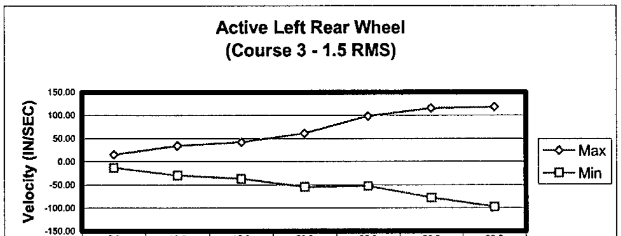
	5.0	10.0	15.0	20.0	25.0	30.0	32.5
Max	18.55	38.22	47.76	72.93	106.50	119.73	118.45
Min	-13.10	-27.14	-36.21	-56.03	-59.68	-83.66	-102.95

Figure 60 - Left Front Wheel Velocity (Course 3)



	5.0	10.0	15.0	20.0	25.0	30.0	32.5
Max	14.37	30.50	43.38	65.83	98.57	112.19	115.95
Min	-11.97	-25.70	-31.59	-39.65	-60.95	-82.66	-108.31

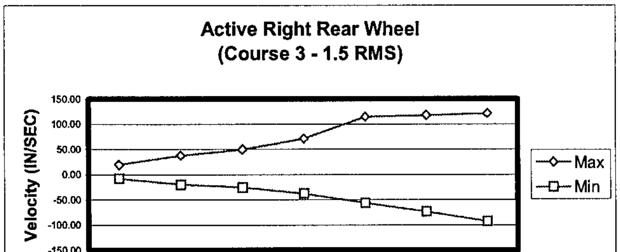
Figure 61 - Right Front Wheel Velocity (Course 3)



	5.0	10.0	15.0	20.0	25.0	30.0	32.5
Max	14.92	34.32	41.75	61.38	98.31	115.58	118.14
Min	-12.77	-28.97	-36.57	-53.90	-51.86	-77.17	-96.48

Speed (MPH)

Figure 62 - Left Rear Wheel Velocity (Course 3)



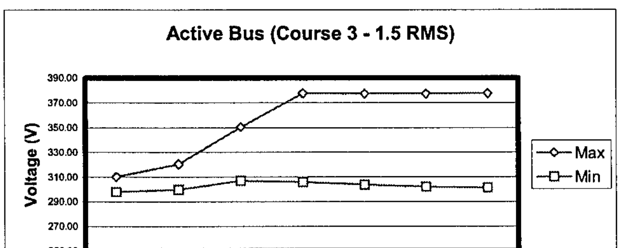
	5.0	10.0	15.0	20.0	25.0	30.0	32.5
Max	18.97	37.51	49.43	71.36	114.30	117.99	121.27
Min	-8.18	-19.72	-25.21	-37.44	-55.69	-72.82	-92.19

Speed (MPH)

Figure 63 - Right Rear Wheel Velocity (Course 3)

Active Power

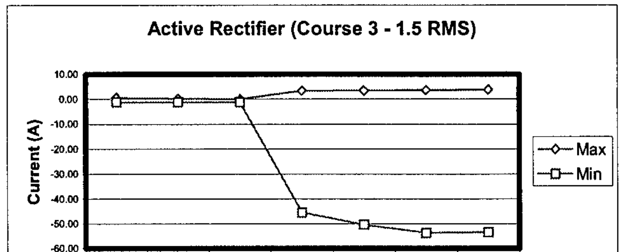
Figures 64 - 67 show (servo amplifier) bus voltage, rectifier current, Pulse Width Modulated (PWM) current, and power consumption. Due to the drifting of the hall-effect current sensors, the PWM current was offset by its mean value so that it was centered around zero (usage and regeneration) to obtain an estimate of the current and power consumption of the EMS.



	5.0	10.0	15.0	20.0	25.0	30.0	32.5
Max	310.22	320.31	350.50	377.59	377.35	377.37	377.66
Min	297.86	299.73	307.00	306.02	303.69	301.99	301.47

Speed (MPH)

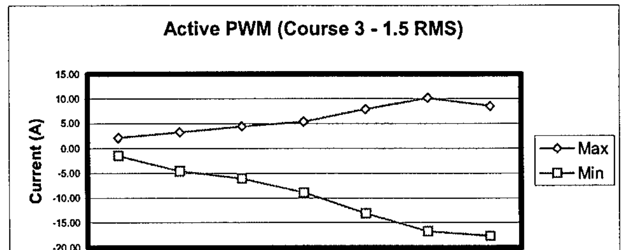
Figure 64 - Bus Voltage (Course 3)



	5.0	10.0	15.0	20.0	25.0	30.0	32.5
Max	0.72	0.29	0.03	3.43	3.49	3.70	3.87
Min	-1.12	-1.13	-1.10	-45.50	-50.40	-53.66	-53.42

Speed (MPH)

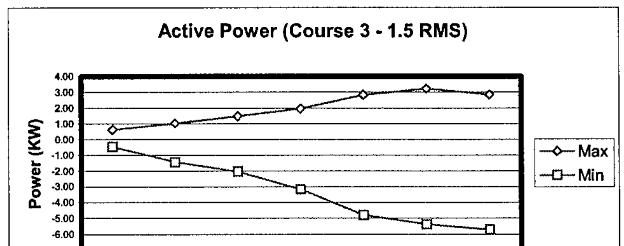
Figure 65 - Rectifier Current (Course 3)



	5.0	10.0	15.0	20.0	25.0	30.0	32.5
Max	2.11	3.26	4.44	5.40	7.84	10.19	8.51
Min	-1.51	-4.59	-6.04	-8.87	-13.12	-16.65	-17.58

Speed (MPH)

Figure 66 - PWM Current (Course 3)



	5.0	10.0	15.0	20.0	25.0	30.0	32.5
Max	0.63	1.02	1.49	1.97	2.85	3.24	2.87
Min	-0.45	-1.43	-2.03	-3.17	-4.78	-5.37	-5.70

Speed (MPH)

Figure 67 - Power (Course 3)

HALF-ROUND BUMPS

The Shock Quality or Half-Round Bump test was not initiated due to the time constraints of the test session. The actuator problems, though inevitable in testing, took more time to remedy than anticipated and in addition, this test session was limited to 3 days instead of 4 due to the Veteran's Day Holiday. As a result, no data was collected for this test.

CONCLUSION

The following give a brief summary of the conclusions that can be made from the test results based on maximum and minimum peak values.

LANE CHANGE MANEUVER

For this test the driver noticed a quicker response from the active EMS HMMWV.

Active and Passive Wheel Travel

Greater wheel travel was noticed in the active HMMWV, upto 2 times in the front. The actuator produces more travel in order

to reduce the forces on the sprung mass. After testing it was thought that one of the rear actuators was not working which may explain the results for the rear wheel travel.

Active and Passive Sprung Mass Acceleration
The active HMMWV has much less sprung mass acceleration, over 5 times reduction at higher speeds, than the passive HMMWV. For the active HMMWV it remains mostly constant to 55 MPH while the passive HMMWV shows noticeable increases.

Active and Passive CG Lateral Acceleration
The values for both are closely aligned and show no significant divergence.

Active Power
The approximate range of the bus voltage was between 260 to 310 volts. Rectifier current reached over 4 amperes while the PWM current went over 12 amperes. Total power usage was in the range of 3 kW.

Passive Roll Rate
As a benchmark, these values approached +/- 10 degrees per second.

Passive Yaw and Steer Angle
As a benchmark, these values approached +/- 20 degrees per second between angles of +/- 3 degrees.

RMS COURSES

Active and Passive Absorbed Power
The comparison shows a 5 times reduction in absorbed power with the active HMMWV.

Active and Passive Wheel Travel
The active HMMWV shows greater travel in the rear which could be attributed to compensation by the suspension to reduce pitching.

Active and Passive Sprung Mass Acceleration
The active HMMWV has much less sprung mass acceleration, over 4 times reduction at higher speeds, than the passive HMMWV. For the active HMMWV it remains mostly constant to higher speeds while the passive HMMWV shows noticeable increases.

Active and Passive Unsprung Mass Acceleration
The values for both are closely aligned and show no significant divergence.

Active and Passive Pitch Rate
The active HMMWV has much less pitch rate, over 5 times reduction at higher speeds, than the passive HMMWV. For the active HMMWV it remains mostly constant to 55 MPH while the passive HMMWV shows noticeable increases.

Active Wheel Velocity
As a benchmark, these values approached +/- 100 inches per second.

Active Power
The approximate range of the bus voltage was between 300 to 375 volts. Rectifier current reached over 50 amperes (regeneration) while the PWM current went over 10 amperes for usage and more than -15 amperes for regeneration. Total peak power usage was in the range of 3 kW while total peak regeneration was in the range of 6 kW.

OBSERVATIONS

For future reference to enable more efficient planning and actual testing, the following observations are offered.

The instrumentation suites were not the same on the active and passive HMMWV's. This proved difficult in trying to determine performance advantages of the EMS since there was not a corresponding signal in each to compare. Specifically, the active HMMWV lacked a steer angle sensor, which would be helpful in determining Lane Change Maneuver performance, and full rate sensors for the CG which resulted in loss of roll rate data collection for the Lane Change Maneuver since the sensor was not orientated from the pitch rate sensing position to roll rate position before testing. Both of these sensors are planned to be procured for future test sessions.

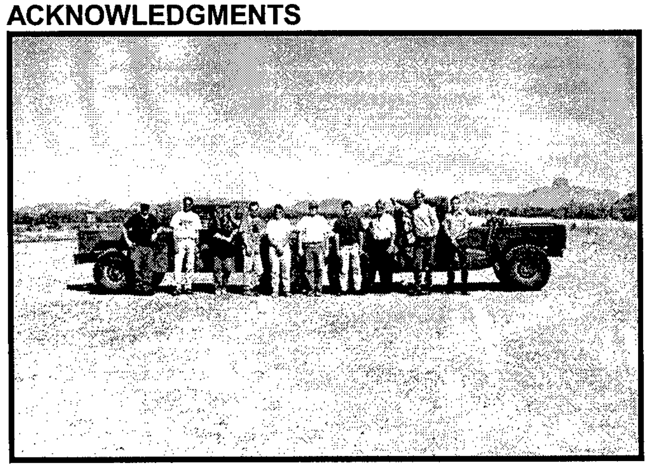
The planned Constant Step Slalom turned out to have a cone spacing too small to allow the vehicle driver to proceed at a reasonable speed. Cone spacing for this test should start at about 65 feet to allow for higher speeds and more meaningful results. To do this test accurately a time trip should be setup at the entry point since the test is supposed to be a timed event.

In the set of RMS Courses course 2 did not represent "natural" terrain and was more like a shock course since it was created by scraping out "ditches" through the length of the course. Courses 3 to 5 provide more realistic cross-country terrain.

The Shock Quality or Half-Round Bumps were not even encountered since the 3 day session was taken up by the other tests and repair on the actuator. A 4 day test session would be recommended at a minimum.

If video is desired to be taken of the back of the vehicle, it is highly recommended that the course be watered down to prevent dust from obscuring the action of the vehicle as it progresses through the course.

ACKNOWLEDGMENTS



The author would like to thank all involved, especially personnel from YPG -- Wayne (Test Director), Scott (Instrumentation), Jim (Data Collection), Cindy (Driver), and Gary (Video).

CONTACT

The author is a project engineer at TACOM. Interested parties can contact the author at the U.S. Army Tank-automotive and Armaments Command, ATTN: AMSTA-TR-R/MS159, Warren, Michigan 48397-5000, bylsmaw@tacom.army.mil.

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DEFINITIONS, ACRONYMS, ABBREVIATIONS

CG - Center of Gravity
EMS - Electromechanical Suspension
HMMWV - High Mobility Multi-purpose Wheeled Vehicle
MPH - Mile per hour
PWM - Pulse Width Modulation
RMS - Root Mean Square
TACOM - U.S. Army Tank-automotive and Armaments Command
TARDEC U.S. Army Research, Development and Engineering Center
UT-CEM - University of Texas Center for Electromechanics
YPG - Yuma Proving Grounds

Resolver - a device that is used to determine the position of the motor rotor/stator to ensure proper motor current commutation to maintain commanded actuator force.

APPENDIX A - Scope of Work

Scope of Work

1 SCOPE. This Scope of Work (SOW) covers technical support and testing services to be provided to the Mobility Directorate of the U.S. Army Tank-automotive and Armaments Command (TACOM). This support encompasses technical work and the use of test facilities.

1.1 Background. TACOM is involved in the development of advanced suspension technology to increase the mobility performance of Army vehicles. The particular application of an electromechanical active suspension (EMS) to achieve increased performance is being explored. Comparison testing between the electromechanical active suspension and a passive system is being sought to quantify the actual performance gains for ride quality, shock, and maneuverability. The platform for this particular test is the High Mobility Multi-purpose Wheeled Vehicle (HMMWV). Three test periods (approx. 1 month separation) are planned for tuning the EMS HMMWV active suspension controller with instrumented testing by the test facility of the passive HMMWV for each test session.

2 APPLICABLE DOCUMENTS.

2.1 Course Layouts. See Appendix A1.

2.2 Testing Procedures. See Appendix A2.

3 REQUIRMENTS.

3.1 General. Use of the test facilities shall include support of test personnel, preparation of test areas or courses in conjunction with tests requested, installation of data collection equipment and instrumentation, and production of test results in digital form on CD-ROM or Zip disk format and video requested. TACOM will coordinate the overall test program with cooperation from the University of Texas-Center for Electromechanics, arrange delivery of the EMS HMMWV. Testing shall begin upon the arrival of the EMS HMMWV. All test results shall be delivered no later than 30 days after final testing is completed.

3.2 Instrumentation. The passive HMMWV vehicle shall be instrumented with sensors mounted on solid non-resonating surfaces to measure the following at the specified location:

3.2.1.1 Vertical acceleration on vehicle body above each wheel (4 sensors)

3.2.1.2 Vertical acceleration on each wheel near knuckle assembly (4 sensors)

3.2.1.3 Differential position of suspension or wheel travel for each wheel (4 sensors)

3.2.1.4 Tri-axial acceleration at CG (vertical, longitudinal, lateral) (1 sensor)

3.2.1.5 Tri-axial angular rate at CG (roll, pitch, yaw) (1 sensor)

3.2.1.6 Speed (longitudinal) (1 sensor)

3.2.1.7 Steering angle (1 sensor)

3.2.1.8 Vertical acceleration at driver's floor (1 sensor)

3.2.2 An Instrumentation Map shall be provided for each test conducted.

3.3 Test Descriptions.

3.3.1 Ride. Ride quality tests shall be conducted according to the test procedure described in the Appendix (A2). Each vehicle shall be driven over the following courses (approx. RMS) starting at 5 MPH in 5 MPH increments (refinement to 2.5 MPH increments may be needed for special cases):

3.3.1.1 Course 2 - 1.3" RMS roughness

3.3.1.2 Course 3 - 1.5" RMS roughness

3.3.1.3 Course 4 - 2.0" RMS roughness

3.3.1.4 Course 5 - 3.4" RMS roughness

3.3.2 <u>Shock</u>. Shock level tests shall be conducted according to the test procedure described in the Appendix (A2). Each vehicle shall be driven over the following, full vehicle width, half-round bump heights starting at 5 MPH in 5 MPH increments (refinement to 2.5 MPH increments may be needed for special cases):

3.3.2.0 4" half-round

3.3.2.1 6" half-round

3.3.2.2 8" half-round

3.3.2.3 10" half-round

3.3.2.4 12" half-round

3.3.3 <u>Maneuverability</u>.

3.3.3.1 <u>Double Lane Change</u>. Double Lane Change tests shall be conducted according to the test procedure described in the Appendix (A2). (For the case of the HMMWV the vehicle length and width shall be 15 ft and 7 ft, respectively). Each vehicle shall be driven over the course starting at 5 MPH in 5 MPH increments (refinement to 2.5 MPH increments may be needed for special cases).

3.3.3.2 <u>Constant Step Slalom</u>. Constant Step Slalom tests shall be conducted according to the test procedure described in the Appendix (A2). Each vehicle shall be driven over the course with the following cone spacing starting at 5 MPH in 5 MPH increments (refinement to 2.5 MPH increments may be needed for special cases):

3.3.3.2.1 d = 10 m (32.8 ft)

3.3.3.2.2 d = 15 m (49.2 ft)

3.3.3.2.3 d = 20 m (65.6 ft)

3.3.3.2.4 d = 30 m (98.4 ft)

3.4 <u>Data Acquisition.</u> All tests shall be run at the specified constant speeds or until deemed unsafe. A check of test data shall be made after each run and if any channel failure or dropout is present that test shall be rerun in entirety. The sample rate will be conducted at 500 Hz and all channel data for each test shall be stored and delivered on CD-ROM or Zip Disk format media in ASCII format (including file content description). Side and frontal video shots shall be taken of each test. A digital profile of all ride courses used shall be provided.

APPENDIX

A1 COURSE LAYOUTS

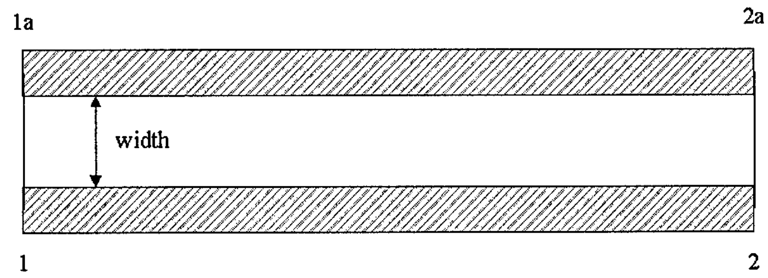

Figure A1 - Ride Course Layout

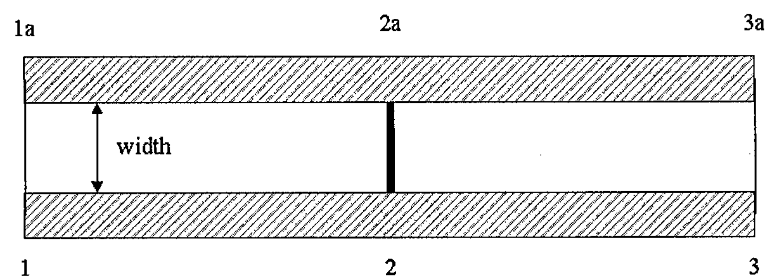

Figure A2 - Bump Course Layout

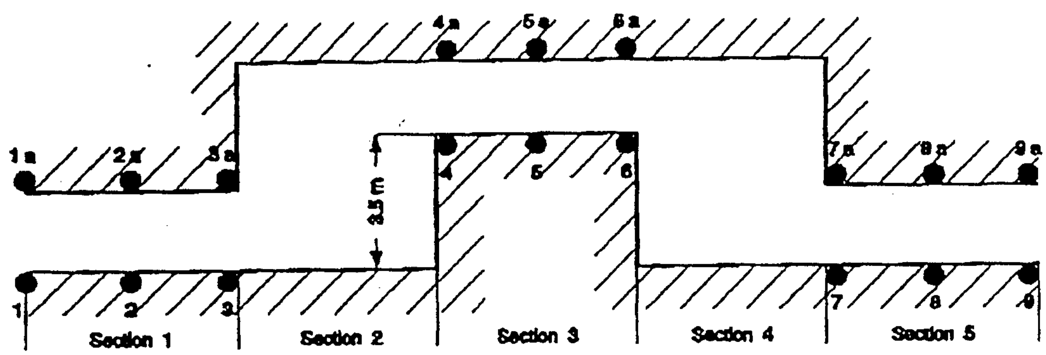

Figure A3 - Lane Change Layout

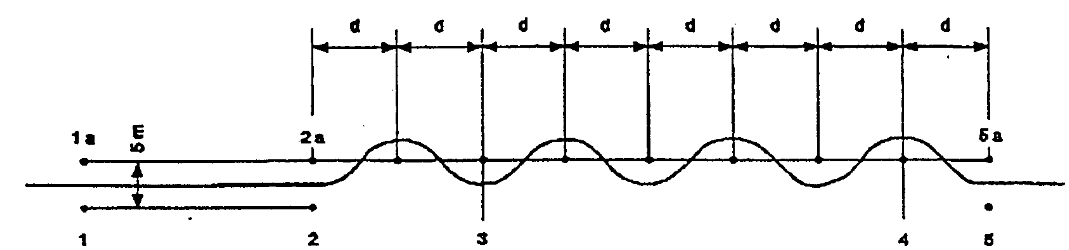

Figure A4 - Constant Step Slalom Layout

A2 TEST PROCEDURES

A2.1 Ride.

A2.1.a Set up the course shown (Figure A1) with width at least two times the vehicle width and with distance (1-2) at least 150 m (492 ft).

A2.1.b Cross the line (1-1a) at the lowest vehicle speed laid down in the test plan and drive in a straight line through the section (1-2); attempt to continue through the remainder of the course whilst keeping the speed as steady as possible at this same value. Record parameters and note the vehicle behavior during the test.

A2.1.c Repeat (b) at the various speed increments laid down in test plan until: 1) maximum speed laid down in the test plan is reached or 2) it becomes impossible to cross the test area without staying on the course or 3) a speed is reached at which there is a risk of the vehicle falling onto its side, whichever occurs first.

A2.1.d Repeat the above procedure (a) to (c), but with the courses roughness as laid down in the test plan.

A2.2 Shock.

A2.2.a Set up the course shown (Figure A2) with width at least two times the vehicle width including a full vehicle width half-round bump at (2-2a).

A2.2.b Cross the line (1-1a) at the lowest vehicle speed laid down in the test plan and drive in a straight line through the section (1-3); attempt to continue through the remainder of the course whilst keeping the speed as steady as possible at this same value. Record parameters and note the vehicle behavior during the test.

A2.2.c Repeat (b) at the various speed increments laid down in test plan until: 1) maximum speed laid down in the test plan is reached or 2) it becomes impossible to cross the test area without staying on the course or 3) a speed is reached at which there is a risk of the vehicle falling onto its side, whichever occurs first.

A2.2.d Repeat the above procedure (a) to (c), but with the half-round bump height as laid down in the test plan.

A3.3 Maneuverability.

A3.3.1 Double Lane Change.

A3.3.1.a Set up the course shown (Figure A3) with the following dimensions:

Section 1: Length = 15 m (49.2 ft)
Width = 1.1 * vehicle width + 0.25 m (0.82 ft)

Section 2: Length = vehicle length + 24 m (78.72 ft)
Width = 3.5 m (11.48 ft) + Section 3 width

Section 3: Length = 25 m (82 ft)
Width = 1.2 * vehicle width + 0.25m (0.82 ft)

Section 4: Length = vehicle length + 24 m (78.72 ft)
Width = 3.5 m (11.48 ft) + Section 3 width

Section 5: Length = 15 m (49.2 ft)
Width = 1.1 * vehicle width + 0.25 m (0.82 ft)

A3.3.1.b Cross the line (1-1a) with the lowest vehicle speed laid down in test plan and drive in a straight line through the first section (1-3); attempt to continue through the remainder of the course (3-9) whilst keeping the speed as steady as possible at this same value. Record parameters and note the vehicle behavior during the test.

A3.3.1.c Repeat (b) at the various speed increments laid down in the test plan until: 1) maximum speed laid down in the test plan is reached or 2) it becomes impossible to cross the test area without knocking the cones down or 3) a speed is reached at which there is a risk of the vehicle falling onto its side, whichever occurs first.

A3.3.2 Constant Step Slalom.

A3.3.2.a Set up the course shown (Figure A4) with distance "d" as laid out in the test plan and with distances (1-1a, 2-2a, 5-5a) at 5 m (16.4 ft).

A3.3.2.b Cross the line (1-1a) at the lowest vehicle speed laid down in the test plan and drive in a straight line through the section (1-2); attempt to continue through the remainder of the course (2-5)) whilst keeping the speed as steady as possible at this same value. The time needed to cross the section (3-4) is to be measured. Record parameters and note the vehicle behavior during the test.

A3.3.2.c Repeat (b) at the various speed increments laid down in test plan until: 1) maximum speed laid down in the test plan is reached or 2) it becomes impossible to cross the test area without knocking the cones down or 3) a speed is reached at which there is a risk of the vehicle falling onto its side, whichever occurs first.

A3.3.2.d Repeat the above procedure (a) to (c), but with the distances "d" set in turn at 15, 20 and 30 m (49.2, 65.6, and 98.4 ft).

APPENDIX B - Test Matrix

		Direction				Test Type								Video				
Test No.	File Name	North	South	East	West	Lane Change	Constant Step Slalom	RMS	Half-round	Speed	Veh. Type (P or A)	Veh. Parameter File	Data Collection	Front	Rear	Veh. Right Side	Veh. Left Side	Comments
																		8 NOV 99
1	001	X				X				20.0	P		X		X			
2	002		X			X				20.0	P		X	X				
3	003	X				X				25.0	P		X		X			
4	004		X			X				25.0	P		X	X				
5	005	X				X				30.0	P		X		X			
6	006		X			X				30.0	P			X				see 036 (YPG 118) (no data)
7	007	X				X				35.0	P				X			see 037 (YPG 119) (no data)
8	008		X			X				35.0	P		X	X				
9	009	X				X				40.0	P		X		X			
10	010		X			X				40.0	P		X	X				
11	011	X				X				45.0	P		X		X			
12	012		X			X				45.0	P		X	X				
13	013	X				X				50.0	P		X		X			
14	014		X			X				50.0	P		X	X				redo, see 015 (bystander distracted driver)
15	015		X			X				50.0	P		X	X				see 014
16	016	X				X				55.0	P		X		X			cones hit
17	017		X			X				55.0	P		X	X				
18						X												practice EMS run
19						X												practice EMS run

20	018	X				X				20.0	A	P01	X		X			* P01=5000 (1st day), P03=1000 (2nd day) P02=0 (3rd day)
21	019		X			X				20.0	A	P01	X	X				* all roll data is pitch data (sensor not switched)
22	020	X				X				25.0	A	P01	X		X			
23			X			X				25.0	A	P01		X				see 021 (no data)
24	021		X			X				25.0	A	P01	X	X				see test #23
25	022	X				X				30.0	A	P01	X		X			flipped cone back in place
26	023		X			X				30.0	A	P01	X	X				
27	024	X				X				35.0	A	P01	X		X			
28	025		X			X				35.0	A	P01	X	X				
29	026	X				X				40.0	A	P01	X		X			
30	027		X			X				40.0	A	P01	X	X				
31	028	X				X				45.0	A	P01	X		X			
32	029		X			X				45.0	A	P01	X	X				
33	030	X				X				50.0	A	P01	X		X			% roll compensation at 100 (tire flex)
34	031		X			X				50.0	A	P01	X	X				
35	032	X				X				55.0	A	P01	X		X			redo 033, driver missed input cones
36			X			X				55.0	A	P01		X				no data - may have actuator fault
37	033	X				X				55.0	A	P01	X		X			*actuator may not have been working
38	034		X			X				55.0	A	P01	X	X				*actuator may not have been working
39		X				X				50.0	A	P01			X			actuator force measurement tests for Joe
40	035		X			X				50.0	A	P01		X				
41	036 (118)		X			X				30.0	P		X	X				see 006
42	037 (119)	X				X				35.0	P		X		X			see 007
																		COMMENTS:
																		Driver noticed quicker response from Active
																		Slower speeds can watch speedometer (for constant speed)
																		Higher speeds (>25-30) watch cones only

																		9 NOV 99
43	101		X				1			5.0	P		X	X				*1=32.8,2=49.2,3=65.6,4=98.4 (feet)/flip course going South
44	102		X				1			10.0	P		X	X				* tried practice runs @ 65 ft - better
45	103		X				1			15.0	P			X				no data (driver disregard)
46	104		X				1			15.0	P			X				no data (not steady speed)
47	105		X				1			5.0	A	P03	X	X				resolver error (analog power fault)
48	201	X						2		5.0	P		X		X			*2=1.3" RMS, 1000 feet (rougher at end)
49	202	X						2		10.0	P		X		X			
50	203	X						2		15.0	P		X		X			
51	204	X						2		20.0	P		X		X			too dusty - video unclear
52	205	X						2		25.0	P		X		X			
53	206	X						2		30.0	P		X		X			part of last 2 seconds corrupted
54	207	X						2		35.0	P		X		X			
55	208	X						2		5.0	A	P03	X		X			
56	209	X						2		10.0	A	P03	X		X			
57	210	X						2		15.0	A	P03	X		X			
58	211	X						2		20.0	A	P03	X		X			
59	212	X						2		25.0	A	P03	X		X			stopped 3/4 way - FL actuator torque slip
60	301	X						3		5.0	P		X		X			*3=1.5" RMS
61	302	X						3		10.0	P		X		X			
62	303	X						3		15.0	P		X		X			
63	304	X						3		20.0	P		X		X			
64	305	X						3		25.0	P		X		X			
																		COMMENTS:
																		rate transducer temperature sensitive
																		manufacturers rating not being met on transtorque
																		roughness issue on surface of inner and outer shaft
																		for video may want to water down courses to avoid dust

																		9 NOV 99
43	101		X				1			5.0	P		X	X				*1=32.8,2=49.2,3=65.6,4=98.4 (feet)/flip course going South
44	102		X				1			10.0	P		X	X				* tried practice runs @ 65 ft - better
45	103		X				1			15.0	P			X				no data (driver disregard)
46	104		X				1			15.0	P			X				no data (not steady speed)
47	105		X				1			5.0	A	P03	X	X				resolver error (analog power fault)
48	201	X						2		5.0	P		X		X			*2=1.3" RMS, 1000 feet (rougher at end)
49	202	X						2		10.0	P		X		X			
50	203	X						2		15.0	P		X		X			
51	204	X						2		20.0	P		X		X			too dusty - video unclear
52	205	X						2		25.0	P		X		X			
53	206	X						2		30.0	P		X		X			part of last 2 seconds corrupted
54	207	X						2		35.0	P		X		X			
55	208	X						2		5.0	A	P03	X		X			
56	209	X						2		10.0	A	P03	X		X			
57	210	X						2		15.0	A	P03	X		X			
58	211	X						2		20.0	A	P03	X		X			
59	212	X						2		25.0	A	P03	X		X			stopped 3/4 way - FL actuator torque slip
60	301	X						3		5.0	P		X		X			*3=1.5" RMS
61	302	X						3		10.0	P		X		X			
62	303	X						3		15.0	P		X		X			
63	304	X						3		20.0	P		X		X			
64	305	X						3		25.0	P		X		X			
																		COMMENTS:
																		rate transducer temperature sensitive
																		manufacturers rating not being met on transtorque
																		roughness issue on surface of inner and outer shaft
																		for video may want to water down courses to avoid dust

APPENDIX C - Passive Sensor Instrumentation List

Passive HMMWV Sensor Locations

(Revised 11-29-99)

Channel #	Sensor	Location	Type	Elements	Direction	Scale Factor	Coordinates (in)	Comments
1	Sprung Acceleration FL1 "Gs"	Front Left Frame	Capacitance Accelerometer	1	Up = Positive	.00496	170,60,26	Endevco 7290A-10, ± 10g, 0-500 Hz
2	Sprung Acceleration FR2 "Gs"	Front Right Frame	Capacitance Accelerometer	1	Up = Positive	.00497	170,23,26	Endevco 7290A-10, ± 10g, 0-500 Hz
3	Sprung Acceleration RL3 "Gs"	Rear Left Spring Bracket	Capacitance Accelerometer	1	Up = Positive	.00501	19,60,31.25	Endevco 7290A-10, ± 10g, 0-500 Hz
4	Sprung Acceleration RR4 "Gs"	Rear Right Spring Bracket	Capacitance Accelerometer	1	Up = Positive	.00496	19,23,31.25	Endevco 7290A-10, ± 10g, 0-500 Hz
5	Wheel Acceleration FL1 "Gs"	Front Left Hub	Capacitance Accelerometer	1	Up = Positive	.01515	154,79,20.5	Endevco 7290A-30, ± 30g, 0-800 Hz
6	Wheel Acceleration FR2 "Gs"	Front Right Hub	Capacitance Accelerometer	1	Up = Positive	.01527	164,5,20.5	Endevco 7290A-30 ± 30g, 0-800 Hz
7	Wheel Acceleration RL3 "Gs"	Rear Left Hub	Capacitance Accelerometer	1	Up = Positive	.01505	27,79,20.5	Endevco 7290A-30 ± 30g, 0-800 Hz
8	Wheel Acceleration RR4 "Gs"	Rear Right Hub	Capacitance Accelerometer	1	Up = Positive	.01527	37,5,20.5	Endevco 7290A-30 ± 30g, 0-800 Hz
9	CG Longitudinal Acceleration "Gs"	Cargo area Sheetmetal between seats	Capacitance Accelerometer	1	Forward = Positive	.00501	91.5,44,36	Endevco 7290A-10, ± 10g, 0-500 Hz
10	CG Lateral Acceleration "Gs"	Cargo area Sheetmetal between seats	Capacitance Accelerometer	1	Left = Positive	.00498	91.5,44,36	Endevco 7290A-10, ± 10g, 0-500 Hz
Channel #	**Sensor**	**Location**	**Type**	**Elements**	**Direction**	**Scale Factor**	**Coordinates (in)**	**Comments**
11	CG Vertical Acceleration "Gs"	Cargo area Sheetmetal between seats	Capacitance Accelerometer	1	Up = Positive	.00498	91.5,44,36	Endevco 7290A-10, ± 10g, 0-500 Hz

12	Driver's Vertical Acceleration "Gs"	Frame crossmember behind seat	Capacitance Accelerometer	1	Up = Positive	.01513	85.5,71.5,34.25	Endevco 7290A-30, ± 30g, 0-800 Hz
13	Pitch "Deg/sec"	Cargo area Sheetmetal between seats	3-Axis Rate Transducer	1	Nose down = Positive	.024	93,44,36	Humphrey Inc. RT02-0274-1 3-Axis Rate Transducer ± 100° / sec
14	Roll "Deg/sec"	Cargo area Sheetmetal between seats	3-Axis Rate Transducer	1	Roll left = Positive	.040	93,44,36	Humphrey Inc. RT02-0274-1 3-Axis Rate Transducer ± 60° / sec
15	Yaw "Deg/sec"	Cargo area Sheetmetal between seats	3-Axis Rate Transducer	1	Nose Right = Positive	.024	93,44,36	Humphrey Inc. RT02-0274-1 3-Axis Rate Transducer ± 60° / sec
16	Wheel Displacement FL1 "Inches"	Front Left Upper A-Arm Ball-Joint	Linear Position Transducer	1	Extension = Positive	.0062	158,69.5,28.25	UniMeasure PA-30-NJC 30 in.
17	Wheel Displacement FR2 "Inches"	Front Right Upper A-Arm Ball-Joint	Linear Position Transducer	1	Extension = Positive	.0062	158,14,28.25	UniMeasure PA-30-NJC 30 in
18	Wheel Displacement RL3 "Inches"	Rear Left Upper A-Arm Ball-Joint	Linear Position Transducer	1	Extension = Positive	.0062	29,69.5,28.25	UniMeasure PA-30-NJC 30 in
19	Wheel Displacement RR4 "Inches"	Rear Right Upper A-Arm Ball-Joint	Linear Position Transducer	1	Extension = Positive	.0062	29,14,28.25	UniMeasure PA-30-NJC 30 in
20	Steering Angle "Degrees"	Steering Gearbox Pitman Arm	Linear Position Transducer	1	Right turn = Positive	.0045	Steering Gear Box Pitman Arm	Space Age Controls Inc. 160-1705 Position Transducer
21	Road Speed "MPH"	Transfer Case speed output inline w/cable	Pulse Encoder	1	N/A	.4608	Transfer Case	ARGO 8-Pulse Speed Encoder

EMS HMMWV Passive Datalogger Channel List

(Revised 1 Dec 99)

#'s	Log	Channel	Equipment	Cal due	"K" Factor	S/N Misc.
5	1	1	Endevco 7290A-30, ± 30g Capacitance Accelerometer	7/30/2000	.01515	14433 Left Front Wheel
6	2	2	Endevco 7290A-30, ± 30g Capacitance Accelerometer	7/28/2000	.01527	15100 Right Front Wheel
7	3	3	Endevco 7290A-30, ± 30g Capacitance Accelerometer	7/30/2000	.01505	15114 Left Rear Wheel
8	4	4	Endevco 7290A-30, ± 30g Capacitance Accelerometer	7/30/2000	.01527	15117 Right Rear Wheel
1	5	5	Endevco 7290A-10, ± 10g Capacitance Accelerometer	9/10/2000	.00496	14357 Left Front Frame
2	6	6	Endevco 7290A-10, ± 10g Capacitance Accelerometer	9/10/2000	.00497	14398 Right Front Frame
3	7	7	Endevco 7290A-10, ± 10g Capacitance Accelerometer	9/10/2000	.00501	14973 Left Rear Frame
4	8	8	Endevco 7290A-10, ± 10g Capacitance Accelerometer	9/10/2000	.00496	14974 Right Rear Frame
9	9	9	Endevco 7290A-10, ± 10g Capacitance Accelerometer	9/10/2000	.00501	14408 CG Triax Long.
10	10	10	Endevco 7290A-10, ± 10g Capacitance Accelerometer	9/10/2000	.00498	14721 CG Triax Lat.
11	11	11	Endevco 7290A-10, ± 10g Capacitance Accelerometer	9/10/2000	.00498	14972 CG Triax Vert.
12	12	12	Endevco 7290A-30, ± 30g Capacitance Accelerometer	5/13/2000	.01513	14981 Drivers Vert.
13	13	13	Humphrey Inc.3-Axis Rate Transducer± 100° / sec (pitch)	N/A	.024	102 CG
14	14	14	Humphrey Inc.3-Axis Rate Transducer± 60° / sec (roll)	N/A	.040	102 CG
15	15	15	Humphrey Inc.3-Axis Rate Transducer± 60° / sec (yaw)	N/A	.024	102 CG
16	16	16	UniMeasure 30" Position Transducer	N/A	.0062	29020165 Left Front Wheel
17	17	17	UniMeasure 30" Position Transducer	N/A	.0062	29020156 Right Front Wheel
18	18	18	UniMeasure 30" Position Transducer	N/A	.0062	29020152 Left Rear Wheel
19	19	19	UniMeasure 30" Position Transducer	N/A	.0062	29020172 Right Rear Wheel
20	20	20	Space Age Controls Inc. Position Transducer	N/A	.0045	Steering Gear Pitman Arm
21	21	21	ARGO Speed Encoder (8-pulse)	N/A	.4608	N/A Transfer Case Output

APPENDIX D - Active Sensor Instrumentation List

M998 Technical Info
Tire Type & Condition - Goodyear Wrangler MT 37 x 12.50R16.5LT M+S (tread depth @ center 0.5")
Differential drain plug height - front 16.75, rear 18.25
Weight - front 3560, rear 3600 (incudes 180 lb driver with 1/3 tank of gas)

HMMWV Sensor Locations

The location of each sensor is referenced to the ground at a point directly below the right rear corner of the vehicle. The right rear corner is 31 in from the ground. The positive x-axis runs along the right side of the vehicle. The positive y-axis runs along the back of the vehicle. The positive z-axis runs vertically out of the floor. coordinates are given in this order: (x,y,z)

Sensor	Location	type	ele	coords (in)	comments	algorithm	orientation and scale
Wheel Acceleration FL1	Front Left Spindle	piezoresistive accelerometer	1	(154,79,21.5)	IC Sensors 3145, ± 20 g, 0-300 Hz, passive low pass filter @ 16 Hz	Instrumentation, wheel hop control	-positive signal accel away from center of the earth -unit (m/s/s)
Wheel Acceleration FR2	Front Right Spindle	piezoresistive accelerometer	1	(164,5,21.5)	IC Sensors 3145, ± 20 g, 0-300 Hz, passive low pass filter @ 16 Hz	Instrumentation wheel hop control	-positive signal accel away from center of the earth -unit (m/s/s)
Wheel Acceleration RL3	Rear Left Spindle	piezoresistive accelerometer	1	(27,79,21.5)	IC Sensors 3145, ± 20 g, 0-300 Hz, passive low pass filter @ 16 Hz	Instrumentation wheel hop control	-positive signal accel away from center of the earth -unit (m/s/s)
Wheel Acceleration RR4	Rear Right Spindle	piezoresistive accelerometer	1	(37,5,21.5)	IC Sensors 3145, ± 20 g, 0-300 Hz, passive low pass filter @ 16 Hz	Instrumentation wheel hop control	-positive signal accel away from center of the earth -unit (m/s/s)
Sprung Acceleration FL1	Front Left Upper Spring/Actuator Bracket	force balanced accelerometer	1	(170,60,27.5)	Columbia Research Labs SA-127S-1, ± 2 g, 0-150 Hz, passive low pass filter @ 16 Hz	roll, pitch, heave, absolute damping, average absorbed power	-positive signal accel away from center of the earth -unit (m/s/s)
Sprung Acceleration FR2	Front Right Upper Spring/Actuator Bracket	force balanced accelerometer	1	(170,23,27.5)	Columbia Research Labs SA-127S-1, ± 2 g, 0-150 Hz, passive low pass filter @ 16 Hz	roll, pitch, heave, absolute damping	-positive signal accel away from center of the earth -unit (m/s/s)
Sprung Acceleration RL3	Rear Left Upper Spring/Actuator	force balanced	1	(19,60,29.25)	Columbia Research Labs SA-127S-1, ± 2 g, 0-150	roll, pitch, heave, absolute damping	-positive signal accel away from center of the earth

	Bracket	accelerometer			Hz, passive low pass filter @ 16 Hz		-unit (m/s/s)
Sprung Acceleration RR4	Rear Right Upper Spring/Actuator Bracket	force balanced accelerometer	1	(19,23,29.25)	Columbia Research Labs SA-127S-1, ± 2 g, 0-150 Hz, passive low pass filter @ 16 Hz	roll, pitch, heave, absolute damping	-positive signal accel away from center of the earth -unit (m/s/s)
Displacement FL1	Front Left Actuator	Linear Variable Differential Transformer	1	Actuator 1	Schavitz 3500 XS-3774, ± 3.5 in, 0-400 Hz, passive low pass filter @ 16 Hz	spring compensation, terrain following, bump stop control	-positive signal when wheel extends -unit (m) @ wheel
Displacement FR2	Front Right Actuator	Linear Variable Differential Transformer	1	Actuator 2	Schavitz 3500 XS-3774, ± 3.5 in, 0-400 Hz, passive low pass filter @ 16 Hz	spring compensation, terrain following, bump stop control	-positive signal when wheel extends -unit (m) @ wheel
Displacement RL3	Rear Left Actuator	Linear Variable Differential Transformer	1	Actuator 3	Schavitz 3500 XS-3774, ± 3.5 in, 0-400 Hz, passive low pass filter @ 16 Hz	spring compensation, terrain following, bump stop control	-positive signal when wheel extends -unit (m) @ wheel
Displacement RR4	Rear Right Actuator	Linear Variable Differential Transformer	1	Actuator 4	Schavitz 3500 XS-3774, ± 3.5 in, 0-400 Hz, passive low pass filter @ 16 Hz	spring compensation, terrain following, bump stop control	-positive signal when wheel extends -unit (m) @ wheel
Motor 1 Resolver	Front Left Actuator	Brushless resolver control transmitter	1	Actuator 1	Harowe 21BRCX-500-J17	motor commutation,realtive damping compensation, terrain following, bump stop control	-positive signal when wheel extends -unit (m/s) @ wheel
Motor 2 Resolver	Front Right Actuator	Brushless resolver control transmitter	1	Actuator 2	Harowe 21BRCX-500-J17	motor commutation,realtive damping compensation, terrain following, bump stop control	-positive signal when wheel extends -unit (m/s) @ wheel
Motor 3 Resolver	Rear Left Actuator	Brushless resolver control transmitter	1	Actuator 3	Harowe 21BRCX-500-J17	motor commutation,realtive damping compensation, terrain following, bump	-positive signal when wheel extends -unit (m/s) @ wheel

						stop control	
Motor 4 Resolver	Rear Right Actuator	Brushless resolver control transmitter	1	Actuator 4	Harowe 21BRCX-500-J17	motor commutation,realtive damping compensation, terrain following, bump stop control	-positive signal when wheel extends -unit (m/s) @ wheel
Lateral Acceleration	Frame Crossmemeber	force balanced accelerometer	1	(88,42,19)	Schavitz LSBC-1Z, ± 1 g, 0-100 Hz, passive low pass filter @ 16 Hz	anti roll control, system identification activation	-positive signal accel to the right when in drivers seat -unit (m/s/s)
Longitudenal Acceleration	Frame Crossmemeber	force balanced accelerometer	1	(92,45,20)	Schavitz LSBC-1Z, ± 1 g, 0-100 Hz, passive low pass filter @ 16 Hz	anti pitch control	-positive signal accel forward -unit (m/s/s)
pitch/roll rate sensor	electronics tray	solid state gyro	1	(94,44,38)	BEI Sensors QRS14-00100-103, ± 100 degrees/s, 0-50 Hz, passive low pass filter @ 16 Hz	instrumentation	-positive pitch raise front -positive roll raises driver -unit (radians/s)
speed transducer	transmission	Unknown	1	(77.5,45.5,30)	Toyota Landcruiser cruise control pickup	instrumentation, system identification activation	-absolute value -unit (mph)
Rectifier current	electronics tray	hall effect	1	NA	FW Bell IHA-150, ± 150 A, 0-50 kHz	instrumentation	-positive is current supplied from alternator
PWM current	electronics tray	hall effect	1	NA	FW Bell IHA-150, ± 150 A, 0-50 kHz	instrumentation	-positive is current supplied to actuators
Buss Voltage	electronics tray	differential voltage divider	1	NA	resistive	system enable, current foldback, system shutdown, electrical power	
Drivers Vertical Acceleration	Frame Cross Member	force balanced accelerometer	1	(85,70,34)	Schavitz LSBC-1Z, ± 1 g, 0-100 Hz, passive low pass filter @ 32 Hz	instrumentation	-positive signal accel away from center of the earth -unit (m/s/s)
CG Vertical Acceleration	Cargo area sheetmetal, between front seats	force balanced accelerometer	1	(94,44,37)	Schavitz LSBC-1Z, ± 1 g, 0-100 Hz, passive low pass filter @ 32 Hz	instrumentation	-positive signal accel away from center of the earth -unit (m/s/s)
CG Lateral Acceleration	Cargo area sheetmetal, between front seats	force balanced accelerometer	1	(94,44,37)	Schavitz LSBC-1Z, ± 1 g, 0-100 Hz, passive low pass filter @ 32 Hz	instrumentation	-positive signal accel to the right when in drivers seat -unit (m/s/s)

CG Longitudenal Acceleration	Cargo area sheetmetal, between front seats	force balanced accelerometer	1	(94,44,37)	Schavitz LSBC-1Z, ± 1 g, 0-100 Hz, passive low pass filter @ 32 Hz	instrumentation	-positive signal accel forward -unit (m/s/s)

I am aware that there is foreign intelligence interest in open source publications. I have sufficient technical expertise in the subject matter of this paper to make a determination that the net benefit of this public release outweighs any potential damage.

Reviewer: FRANCIS HOOGTERP GS-15 TEAM LEADER
Name Grade Title

Francis B. Hoogterp
Signature

Date May 18, 2000

Description of Information Reviewed:

Title: Electromechanical Suspension Performance Testing

Author/Originator(s): W. Bylsma

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An abstract, summary, or copy of the information reviewed is available for review.

Reviewer's Determination (circle one):

1. Unclassified Unlimited.

2. Unclassified Limited, Dissemination Restrictions IAW __________.

3. Classified. Cannot be released, and requires classification and control at the level of __________.

Security Office (AMSTA-CS-S):

Concur/Nonconcur
Signature

12 JUNE 2000
Date

Public Affairs Office (AMSTA-CS-CT):

Concur/Nonconcur
Signature

14 JUN 00
Date